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AN INVESTIGATION OF HAND QUALITY PICKING
OF SMALL OBJECTS

A THESIS

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the Faculty of the Graduate Division
Georgia Institute of Technology

In Partial Fulfillment
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Master of Science

By
Hans Richard Zimmer

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AN INVESTIGATION OF HAND QUALITY PICKING

OF SMALL OBJECTS

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ABSTRACT

The national peanut processing industry spends approximately 1.2 million dollars anually in hand quality picking Spanish and Runner type peanuts for the edible market. Other industries using hand quality picking operations, such as coffee and fruit processing, are faced with similar high picking and grading costs.

The aim of this thesis was to refine the basis for selecting successful operators and for the determination of hand quality picking conditions which maximize the picking rate. In more specific terms, the following are the objectives of the thesis:

1. To select tests which discriminate between aptitude characteristics of successful and unsuccessful hand quality pickers.

2. To determine an index of correlation between test performance and an operator's picking rate.

3. To develop density - belt speed combinations which result in optimum picking rates and high picking quality for

    a. A constant rate of flow of objects,
    b. Damage contents,
    c. Operators grouped into classes according to their scores of selected aptitude tests.

By means of aptitude tests nine operators, from a total of 47 students of the Georgia Institute of Technology, were chosen as experimental subjects. They were grouped by scores into three classes (quartiles) from each of which three students were chosen at random as experimental subjects. The experiments were conducted in the laboratory

of the School of Industrial Engineering using Great Northern beans as objects in the experiments.

A factorial, mixed model experiment was designed to examine the following independent variables:

1. Three classes of operators based on aptitude scores,
2. Three operators within each of the classes,
3. Four density - belt speed combinations for a constant rate of flow,
4. Two damage contents,
5. Two replications,

while the succeeding independent variables were held constant:

1. Operator position relative to the picking belt (side position),
2. Picking method ("pick and throw" method).

From a statistical and graphical analysis of the experimental data the following conclusions were drawn:

1. A battery of psychological tests was found to discriminate between aptitude characteristics of good operators (class 1, upper quartile) and average operators (class 2 and 3, middle quartiles). The battery consisted of the following tests:
    a. The Purdue Pegboard Test, Right plus Left plus Both Hands Test and Assembly Test,
    b. The Moore Eye-Hand Coordination and Color-Matching Test,
    c. The Bausch and Lomb Visual Classification and Placement Test.
2. An index of correlation between the scores on the battery of tests and the operators' picking rates of defective objects was found to be .877. This index is significant at the .001 probability level of linear correlation coefficients.
3. Optimum picking rates and high picking quality, for a rate of flow of 7.75 pounds of objects per minute,

were found to result from a density of 22 per cent and a belt speed of 46 feet per minute for all operators and both damage contents.

Recommendations were given leading to further refinement of hand quality picking of small objects:

1. Different flow rates, particularly higher rates, should be investigated.

2. The battery of tests should be validated on experienced female operators.

3. A learning effect should be minimized in the experimental data.

4. Experimentation should be extended to the use of other objects besides Great Northern beans.

5. Smaller belt widths should be investigated.

CHAPTER I

INTRODUCTION

General.-- A large number of business enterprises of the Southern States compose what is referred to in this study as the peanut processing industry. In this specific industry a large annual labor expense is incurred in the buying and marketing of its products. Damaged objects and foreign material are hand picked in processing the peanuts for the edible trade market. This "quality picking accounts for approximately one-half of the total labor costs and about one-fifth of the total processing costs in shelling farmer's stock peanuts." (1)

In economic studies of the year 1952 it was found that the cost for the removal of each one per cent of damaged peanuts, farmers' stock basis, from one ton of farmers' stock Spanish peanuts was seven dollars (2). Furthermore it was estimated that, due to the difference in size and weight of Runner-type and Spanish-type peanuts, it costs about five dollars to remove each one per cent of damage, farmers' stock basis, from one ton of farmers' stock Runner-type peanuts. Because of an average damage content of 1.05 per cent, farmers' stock basis, to be removed from Spanish and Runner peanuts (3), and a national yield of, for instance, 191,000 tons of these two types of peanuts milled for the edible trade market in the year 1952 (4), an approximate total labor cost of 1.2 million dollars occurred for the necessary hand quality picking operation on these two commodities.

The magnitude of such a yearly expense for a single operation suggests a wide field for economic investigations. Other industries are faced with similar analyses as, for instance, the coffee processing industry with its hand quality picking operation, the fruit processors with their closely allied grading operation, and many others.

Statement of the Problem.-- With the exception of an exploratory study made by Calhoun (5) and the investigations conducted by Moder and associates there has been no published literature on which to establish a basis that will allow making decisions to minimize the cost of hand quality picking. This thesis aims to base its experimentation upon the results of these earlier studies and aims to search for a more refined basis for the determination of optimum hand quality picking conditions.

CHAPTER II

PRESENT STATUS OF THE PROBLEM

A short description of the hand quality picking operation will be presented, followed by a critical review of previous investigations which studied each factor influencing the output of this operation or intimately related problems.

Description of the Problem.-- In general terms the operation of hand quality picking is as follows: The objects to be quality picked are presented to the operator by means of a conveyor belt. The damaged objects are to be recognized and picked by the operator as they move within his reach and are to be placed aside. The number of defective objects picked per minute and the per cent of good objects in the pickouts determine the rate and the quality of the picking operation, respectively.

Attack of the Problem.-- A brief consideration of the problem may suggest its adequate treatment by a motion and time study. Malcom and DeGarmo (6) however, in a study on visual inspection of products for surface characteristics in grading operations, raised valid objection to such an analysis of the problem. For two major reasons usual work measurement methods are of questionable value in determining optimum work and labor requirements for grading operations as the operation is currently performed:

1. The task can not be standardized because defective objects usually are randomly spaced and are haphazardly presented to the inspector's visual field.

2. The measurement of visual reaction-decision time on the part of an inspector would be difficult, if not impossible, by the suggested method because grading involves subjective, internal work that is not observable by outward physical indicators.

Individual time standards for grading would therefore be difficult to determine because the grading job itself cannot be defined in terms that are completely observable and hence measurable in units of time.

The logical attack of the problem is the determination of significant factors involved in the picking operation through experimental investigation. Once these factors and their relative magnitude are known the optimum picking conditions for specific industrial situations can be established. Each factor will be discussed separately.

Operator.-- A significant difference in the pickout rates of the operators has been found by Calhoun (7). In this study, a difference of 14.2 per cent between the slowest and the fastest of four experienced operators,based upon the average pickout rate, was found. This result substantiates similar findings by Kovak (8) in an earlier study of this subject, which leads to the conclusion that it might be successful to devise testing procedures for the selection of operators best suited for quality picking. Two principal factors account for the large differences of the operators' picking rates: first, the visual reaction-decision time in which the operator decides which of the objects should be picked out and second, the manipulative skill with which the operator reaches for, picks out, and places the object aside.

In extensive tests on visual impression time it was found that the briefest interval of time that is possible for an observer to fixate an object in order to gain an adequate visual impression was, on the average, 0.17 seconds (9). It therefore can be assumed that, due to a minimum visual impression time, there exists a maximum picking rate for each individual operator which normally may not be exceeded (10). Visual impression time for small objects is dependent upon good vision. The importance of good vision has been amply demonstrated by Tiffin (11) who found high correlation between the test scores of visual acuity tests and, for instance, the accuracy of inspection of tin plate inspectors, or the hourly output of hosiery loopers, respectively.

In an exploratory study Fleishman and Hempel (12) describe the isolation of five common factors which were identified to account for performance on fifteen different tests of dexterity. According to their definitions, the following three factors seem to be of primary importance in the picking operation:

1. Manual dexterity, representing the ability to make skillful arm and hand movements.

2. Finger dexterity, defining the ability to coordinate finger movements in performing fine manipulations.

3. Aiming, identifying the ability to perform quickly and precisely a series of movements requiring eye-hand coordination.

Pace.-- In analyzing experimental data it is of vital importance that these data are collected under precisely known conditions. The pace (or speed) at which the operator performs a certain task is difficult to maintain at a specific level. In studies on basic manual motion patterns it has been found, however, that performing a task at a very fast speed results in less variation in time (inconsistency) than at a lower speed (13).

Fatigue.-- Viteles investigated the effect of fatigue upon the rate of production. He found that the curve of industrial output varies with the operator and with the kind of work done. In comparing skillful and dextrous work with ordinary, non-strenuous work, such as is found, for instance, in a machine shop, Viteles made the following remark: "When the work is characterized by skill and dexterity, there is a slower, more gradual rise to the maximum, followed by a less obvious fall during the morning, a less complete recovery after luncheon, and a much smaller drop at the close of the afternoon." (14) With proper working conditions and rest pauses used in this study it is felt that the effect of fatigue upon the investigated hand picking operation is likely to be so small that it could be omitted as a significant factor.

Work Place.-- Two variables, the work-surface height and the illumination of the work place, are regarded to affect significantly the picking rate. Each variable should be discussed separately.

Work-Surface Height: Ellis (15) found a high consistency among forty-eight male subjects tested in his studies of manipulative performance, feelings and locus of muscular strain, and subjective judgement of preference to work-surface height. The resulting average work-surface height for male subjects corresponds to an average distance of approximately three inches below the elbow. Even if the task, that the conclusion is based upon, lasted only a short period of time the results are considered to be valid because of their close agreement with empirical values (16).

Illumination: The intensity of illumination at the work place affects the time required for seeing. If the certainty of seeing a given object is to be increased from threshold (point of minimum vision) to one hundred per cent certainty, the time available for seeing must be doubled (17). This statement, applied to optimum conditions for the picking operation, could be reworded as follows: The intensity of illumination must be of such magnitude that the minimum visual impression time of the individual operator is sufficient to see the defective objects. Marks (18) recommends for inspection work an illumination level between 30 and 100 foot candles at the work-surface. For picking small objects an average intensity level of 65 foot candles is regarded to be satisfactory.

Operator Position.-- Two variations of the positions of the operators in reference to the conveyor belt are found to be in common use. In "group-picking" several operators are stationed along each side of the conveyor belt along which the peanuts pass. This position is referred to as side position. In "individual picking" one operator is located at the end of the conveyor belt which moves the peanuts towards him. This position is known as end position.

In laboratory tests Moder and Dwyer (19) found that by using the end position significantly higher picking rates can be obtained than with the side position. However, since a change in the picking method was included in these tests, no direct substantiation of the increased picking rate due to end position could be proved. Calhoun (20) found in his factory experiments with experienced operators that half of his subjects had better picking rates with the side position, the other half had a higher rate with the end position. The average increase in the picking rate of the operators favoring the side position was 3.7 per cent, while the average increase of the group favoring the end position was only 1.2 per cent, based upon the grand average picking rate of all operators.

Calhoun's results are backed by a study by Kephart and Besnard (21) on visual differentiation of moving objects. These investigators found that the actual discrimination of moving objects is much easier when these objects are viewed from the side rather than when they are viewed coming towards the subject.

Picking Method.-- The most common picking method found in the peanut industry is termed the "roll" method. In this picking method the operator picks the objects with thumbs and fore-fingers of both hands, rotates the hands and releases the objects into the palms of the hands. These motions are repeated until the hands are full and then the objects are tossed aside.

In the second method the damaged objects are picked with both hands as described above and are then immediately thrown aside, with a simple wrist movement, into a container. This method is called the "pick and throw" method.

Calhoun (22) found for the "pick and throw" method a significantly higher pickout rate than with the "roll" method. The difference was 8.3 per cent, based upon the grand average pickout. With this picking method all his operators proved to be consistently superior at every level tested.

Rate of Flow of Objects.-- One measure of the rate of flow is the weight of objects passing an operator per unit of time. This measure can be defined by the following equation:

$$\text{Rate of Flow (lbs/min)} = \text{Belt Speed (ft/min)} \times \text{Belt Width (ft)}$$

$$\times \text{ Density of Objects on Belt} \left[\frac{\text{wt of obj/ft}^2}{\text{wt of obj/ft}^2}\right]$$

$$\times \text{ Weight of Objects (lbs/ft}^2\text{)}$$

In the above formula the density of objects on the belt is the ratio of the actual weight of objects per unit area of the belt over an experimentally derived weight of objects per unit area representing 100 per cent density. This ratio can be established by weighing the number of objects placed in such a manner in the unit area that there is no more room for more objects without their having to rest on top of others. The weight of objects in the above formula is the total weight of all objects in the unit area with 100 per cent density.

With a constant rate of flow and fixed experimental conditions (belt width and weight of objects) it is possible to arrive at an infinite number of different density - belt speed combinations. The reason for this becomes obvious by examining the rate of flow formula; an increase in belt speed, for instance, has to result in a decrease of the density of the objects on the belt and vice versa. The importance of both of the variables is discussed below.

Moder (23) found in laboratory tests that the belt speed, when varied between 10 and 60 feet per minute, did not appreciably affect the picking rate when a sufficient number of objects was delivered to keep the operator busy. On the other hand, Calhoun realized in factory experiments that operators reacted significantly different to a change in the belt speed. His study was limited to the investigation of only two different belt speeds, a fact which makes it impossible to determine exactly which belt speed results in optimum picking rates.

In Calhoun's study the density and the damage content of the objects were investigated as one combined variable with constant products. The results showed that the lowest of the three investigated levels, which had a density of 33.3 per cent and a damage content of 4 per cent, did more than any other factor to improve the picking rate (24). The findings again are limited because of the possibility of more favorable levels of densities lower than 33.3 per cent and damage contents higher than 4 per cent.

Damage Content.-- The damage content is the percentage, figured on a weight basis, of the objects in question that are damaged. Moder (25) found in his studies that the average damage contents of Spanish-type and Runner-type peanuts of the crops of 1949 to 1952 ranged from 0.80 per cent to 3.76 per cent, based on farmers' stock.

As mentioned above, Calhoun found his highest investigated level of 4 per cent damage content to be the most favorable one for an optimum picking rate. The reason for an increase in the pickouts when the damage content is increased is the fact that the operator spends less time searching for a defective object when a greater number of these defective objects are presented to him. It would be unrealistic in an investigation of optimum picking conditions to study damage contents higher than the average levels harvested in former years.

Summary.-- In the discussion of the factors influencing hand quality picking, a review was given of previous investigations of this and closely related problems. An attempt was made to point out the results and limitations of these studies which form the basis and indicate the direction for this study.

CHAPTER III

OBJECTIVE

This study is intended to fulfill two major needs for the refinement of the hand quality picking operation. First, it seeks to determine if aptitude tests can reveal an operator's success in hand quality picking. Second, it seeks to establish a certain density - belt speed combination which results in optimum picking rates and high quality of the pickouts for given damage contents and a constant rate of flow.

In more specific terms, the following are the objectives of this thesis:

1. To select tests which discriminate between the aptitude characteristics of successful and unsuccessful hand quality pickers.
2. To determine an index of correlation between the scores on the tests employed and the operators' picking rates.
3. To develop density - belt speed combinations which result in optimum pickout rates and high quality of pickouts for
    a. A constant rate of flow of objects,
    b. Damage contents,
    c. Operators grouped into classes according to their scores of selected aptitude tests.

For assurance that the answers to the above stated objectives are not the results caused by chance variation in the pickouts of the individual operators, the following hypotheses are to be tested at a significance level of .05 per cent:

1. That the average picking rates of the operators grouped into classes according to their scores on aptitude tests are not significantly different.

2. That there is no significant difference in the picking rates due to an effect of the tested density - belt speed combinations.

3. That picking from lots with different damage contents does not result in significantly different picking rates.

A factorial mixed model experiment is to be employed to test the above stated hypotheses.

CHAPTER IV

EXPERIMENTAL DESIGN

In this chapter a brief description is given of the experimental subjects tested in the experiment, of the tests employed in their selection for the study, and of the apparatus and objects used for the control of the variables under investigation.

Subjects.-- Nine male experimental subjects were selected from a total of 47 Junior students of the Georgia Institute of Technology. None of the subjects was skilled in hand quality picking of small objects. Their ages varied from 19 to 24 years.

The basis of selection was a manual dexterity test, the Purdue Pegboard, which was given to all 47 students. The histogram of the average score on the four individual pegboard tests is given in Figure 13, Appendix I. More details of the test will be discussed later. The students were grouped according to their test scores into four quartiles; no score was obtained in the lowest quartile. From each quartile three students were chosen in a random manner giving a total of nine subjects grouped into three classes.

Tests.-- Tiffin made the following remark with regard to testing: "It is a general principle of testing that usually no single test is sufficient for the prediction of job success. Just as most jobs call for a combination of aptitudes, so an adequate placement calls for a combination of psychological tests." (26) The previously discussed aptitude characteristics led to the selection of a battery of tests, they are:

1. The Purdue Pegboard, Right Hand Test, Left Hand Test, Both Hands Test, and Right plus Left plus Both Hands Test for manual dexterity.

2. The Purdue Pegboard, Assembly Test for finger dexterity (27).

3. The Moore Eye-Hand Coordination and Color-Matching Test for aiming (28).

4. The Bausch and Lomb Visual Classification and Placement Test for visual skills (29).

In each of the dexterity tests the subjects were tested and retested using a one-trial run in both tests. The first test was conducted before the experimentation and 15 days later the re-test was given. The average score on first and second of the individual dexterity tests was used for correlation purposes. Table 5, Appendix I, gives the scores on these tests.

A passing score on the Bausch and Lomb vision test was a predetermined requirement for acceptance of the selected students as experimental subjects. Figure 14, Appendix I, shows a combination of the visual profiles, as recommended by the Bausch and Lomb Company, for inspection and machine work (30) which was regarded to be representative of the visual skills necessary for the picking operation. More information is given in Appendix I about the test.

Apparatus.-- For the experimental control of the variables in his investigation, Calhoun (31) designed and constructed a special picking table which was regarded as adequate and therefore was used for this study. The picking table consists of four component parts: the frame, the belt carrier, hopper and feed control, and drive.

Frame: The frame, constructed of galvanized iron pipe, supports the picking table and gives a work-surface height of approximately three inches below the average height of elbows when the subjects are in standing position.

Belt Carrier: The belt carrier forms the picking table and consists of 2" x 8" dressed lumber as aprons and main support, with a 12 inch wide 2-ply plastic coated, green endless belt for conveying the objects. A 1/2" plywood sheeting nailed to spacers between the aprons gives a steady base for working surface below the belt. A groove in the apron enables the easy removal of a 22 inch long galvanized iron receptacle in order to count the number of pickouts which were tossed into it by the subject (Figure 1).

Hopper and Feed Control: A hopper, with a feed control as an integral part, is constructed of galvanized sheet iron and is supported by a welded angle iron frame. The frame is designed for adjusting the hopper laterally and horizontally (Figure 2). A 12 inch brush in front of the hopper opening gives an <u>even</u> flow, while a vertically adjustable aluminum gate regulates, in combination with the belt speed, the <u>rate</u> of flow of the objects onto the belt. The gate is calibrated against a marker which is fastened to the hopper in order that each density level can be quickly established. For the calibration of the gate see Appendix II.

Drive: A variable speed, fluid coupled drive of 3/4 HP capacity allows an easy and rapid control of the belt speed. A 1/2 HP electric motor furnishes power for the drive through a "V" belt (Figure 3).

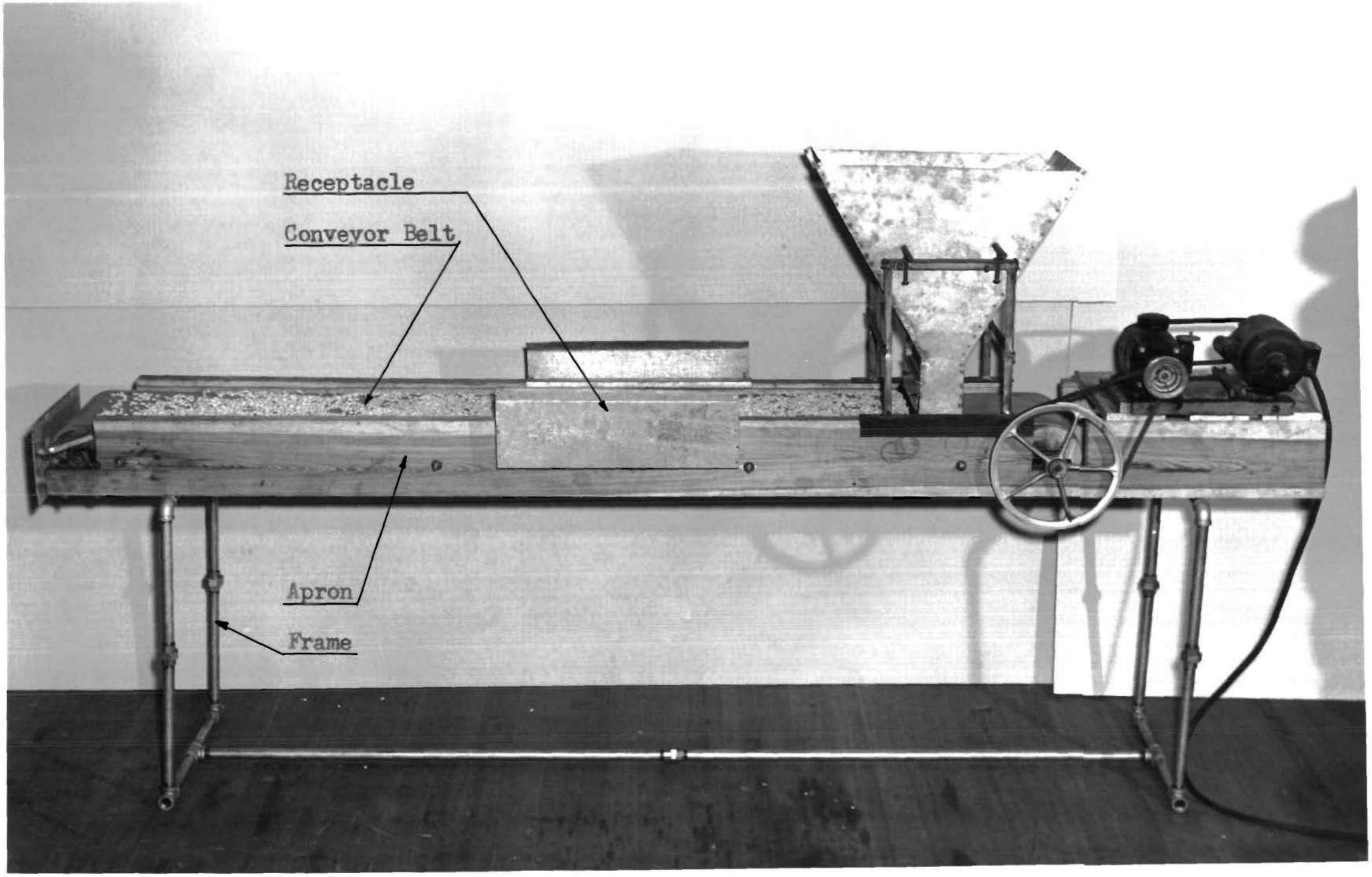

Figure 1. The Experimental Apparatus

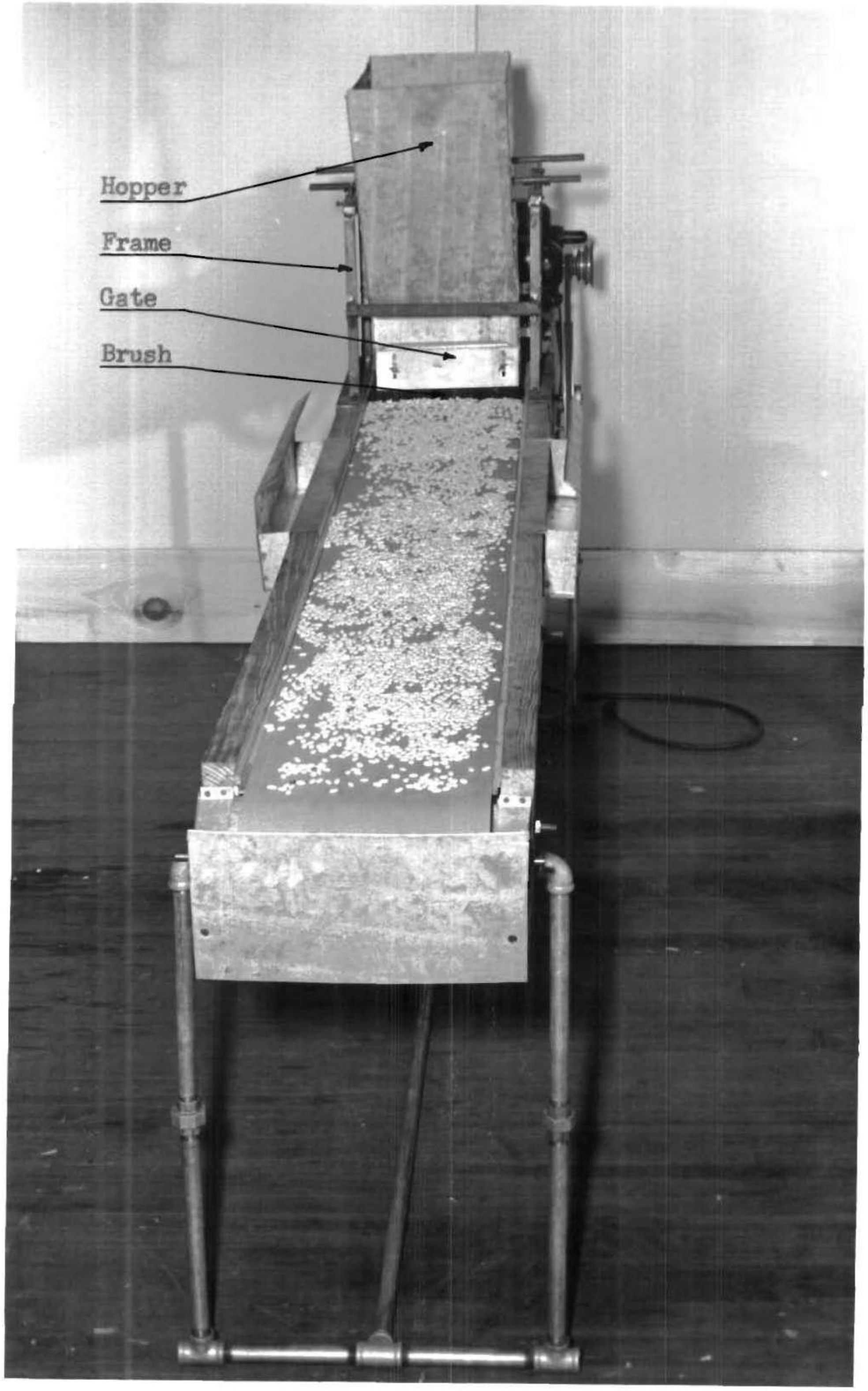

Figure 2. The Hopper and Feed Control of the Experimental Apparatus

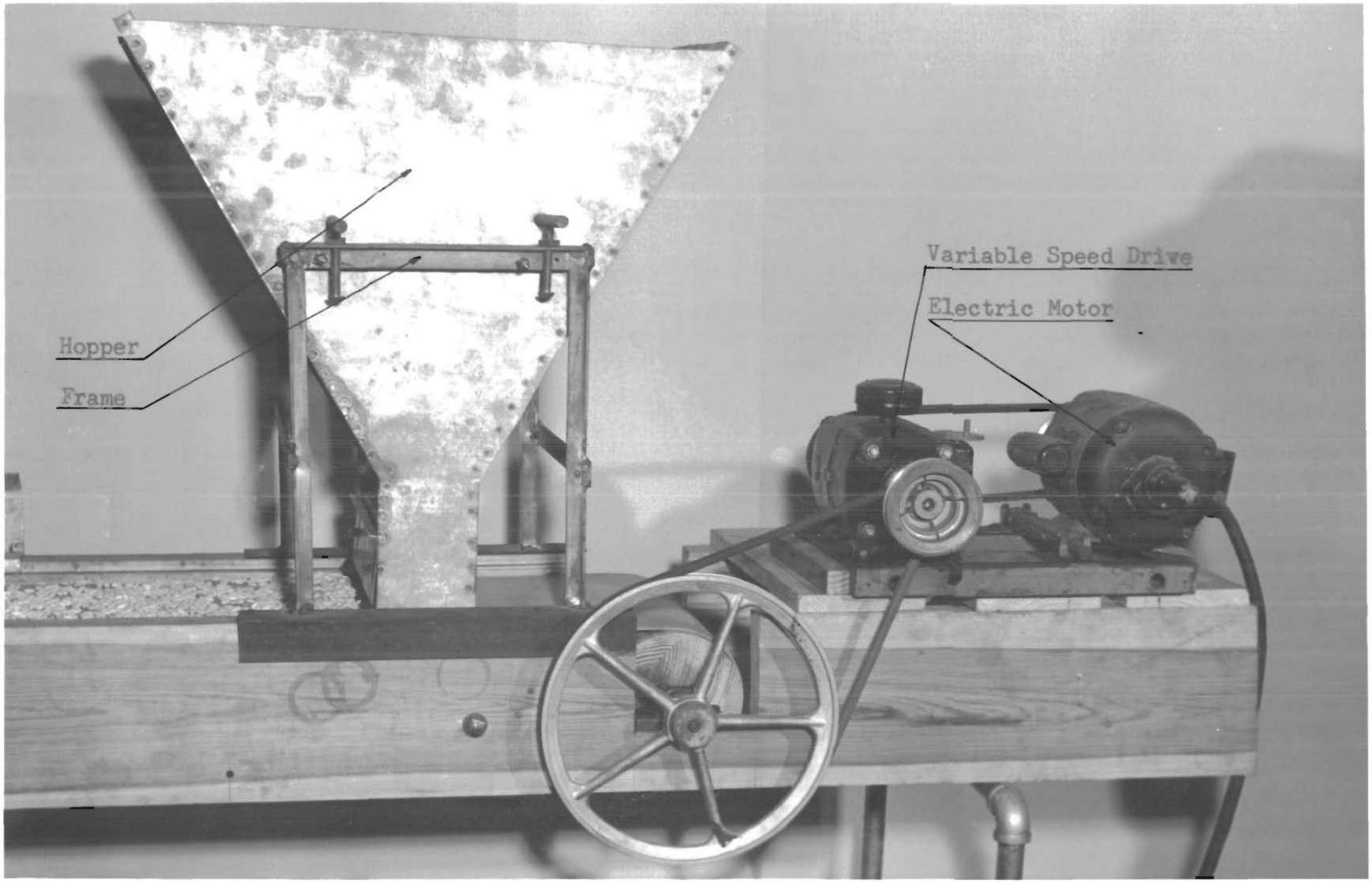

Figure 3. The Drive of the Experimental Apparatus

Objects.-- Great Northern beans were selected for the small objects to be picked in the experiments. Because of their form, hardness and resistance to wear and decay, they were considered to be suitable for representing small objects in the experiments. The beans representing damaged kernels were dyed red. They were mixed with the undyed beans to form lots of the selected damage contents on a weight basis.

CHAPTER V

EXPERIMENTAL PROCEDURE

An outline is given of the factors and their levels studied in this investigation, followed by a description of both the general conditions existing during the experimentation, and the conduct of the experiments. A time table of the conduct of the experiments is also included.

Variable Factors.-- The following factors were studied at the indicated levels:

1. Class.-- Three.

   Each class is represented by a number of subjects whose scores on the Purdue Pegboard tests fall within the following quartiles:

   Class 1.-- 75 to 100 per cent,
   Class 2.-- 50 to 75 per cent,
   Class 3.-- 25 to 50 per cent.

2. Operator.-- Three.

   This factor is the number of subjects within each class.

3. Density - Belt Speed.-- Four.

   The product of density - belt speed is a measure of the rate of flow of the objects upon the belt which was held constant throughout the experiments. Four combinations of density - belt speed were studied which are listed on the following page. For the derivation of the rate of flow, a belt width of one foot and an experimentally derived weight of the objects of 350 gram per sq. ft. (See Appendix II) representing 100 per cent density, were used.

Density - Belt Speed Combination	Density (per cent)	Belt Speed (feet per min.)	Rate of Flow (lbs. per min.)
1	100	10	7.75
2	25	40	7.75
3	15	70	7.75
4	10	100	7.75

4. Damage Content.-- Two.

   This factor is the percentage of defective objects in the material presented to the operator for picking.

   Damage Content 1.-- 2 per cent,
   Damage Content 2.-- 4 per cent.

5. Replications.-- Two.

   The complete experiment was performed two times.

Constant Factors.-- Two factors were standardized throughout the experiment: The position of the operator on the belt and the method of picking the defective objects.

Operator Position: The difference in the effect of side and end position upon the picking rate has been found to be very small. There is still no valid answer as to which position actually results in a higher picking rate. It may be assumed that one picking table for several operators results in lower initial costs than individual picking tables for each of the operators. An assumed small superiority of the end position might therefore be more than offset by higher operating costs in regarding the total costs of quality picking. The side position is in common use in industry, for this reason it was felt that the standardization of this factor is justified.

Picking Method: The "pick and throw" method proved to have a significant effect upon the picking rate at all investigated levels of previous studies. This fact justifies the standardization of this particular picking method. The experimental subjects were instructed to perform the following motions:

Left Hand	Right Hand
Search with eyes to find defective	
Move hand to defective	Move hand to defective
Grasp defective with thumb and fore-fingers	Grasp defective with thumb and fore-fingers
Hold defective in fingers	Hold defective in fingers
Search with eyes to find defective	
Move hand to defective	Move hand to defective
Grasp defective with thumb and fore-fingers	Grasp defective with thumb and fore-fingers
Throw defectives into container with simple wrist movement	Throw defectives into container with simple wrist movement
(repeat)	(repeat)

General Conditions.-- The experiments were conducted in the Laboratory of the School of Industrial Engineering, Georgia Institute of Technology. The laboratory was well ventilated and adequately lighted. Temperature and humidity were at comfortable levels throughout the experiments. A special frame with mounted lighting fixtures, which provided 65 foot candles of light at the working surface, was suspended above the picking table.

Conduct of the Experiment.-- The limited availability of the subjects did not permit the design of the experiments in a rigorous random manner.

The following were the compromises to complete randomization:

1. The order of the subjects was directed by their availability.

2. All tests, performed in a continuous sequence, were given in one day with the exception of second runs on two subjects.

3. Both levels of the damage content were tested after setting each of the density - belt speed combinations in order to keep a variation in the pickouts, due to the adjustment of a density - belt speed level, at a minimum.

In addition to the random selection of the subjects from a group of students having scores on the dexterity tests falling within one quartile, the sequence of testing was assigned to the following factors from a table of random numbers:

1. Density - belt speed combinations of all first runs.

2. Density - belt speed combinations of all second runs.

3. Damage contents within each density - belt speed combination.

The subjects participated in the experiments on a non-financial, voluntary basis which amply proved their interest in the study. They exhibited a helpful attitude in performing the tests and followed all instructions given to them. A twenty-minute trial period, in order to become familiar with the picking operation, had to be sufficient because of the limited available time of the subjects. The subjects were instructed to work consistently at a brisk pace throughout the experiments, a speed defined as the maximum working pace just below the level where fumbling begins. The speed can be compared to the pace held throughout the dexterity tests.

The conduct of an experimental run may be described as follows:

The density - belt speed combination and the damage content were read from the experimental plan which was prepared prior to the conduct of the tests. The desired belt speed was adjusted and checked by means of a tachometer. The density to be tested was located at the specific calibration mark and then the gate was fixed at that position. The lot of beans with the desired damage content was placed into the hopper and the motor was started. At a signal "go" the operator began picking and a decimal minute stop watch was set into action. After four minutes elapsed, a signal "stop" was given to end the picking. The receptacle with the pickouts was removed from the apron of the table and the number of defectives and number of good objects in the pickouts were counted and recorded. The machine was stopped after the hopper was empty and the pickouts were thoroughly mixed with their original lot.

The subject was standing during the four-minute run of an experiment. He was sitting and resting during the counting and recording of the pickouts and during the adjustment of the variable speed drive and gate opening for a new speed and density, respectively. This setup time between the runs lasted for about five to eight minutes.

Time Table.-- Previously it was pointed out that the availability of the subjects was a limitation in the complete randomization of the experiments. For the same reason the time of experimentation varied between the subjects. Generally it can be said that the subjects were given all 16 four-minute runs within approximately four hours of time between 1:00 PM and 7:00 PM. A coffee break of fifteen minutes separated the first and second runs of the tests. The time schedule of experimentation was as follows:

Class	Operator	Week of Experimentation	Time of Experimentation
1	1	1	Wednesday afternoon
1	2	1	Wednesday and Thursday aft.
3	1	1	Thursday afternoon
3	2	1	Friday afternoon
2	1	1	Saturday afternoon
2	2	2	Tuesday afternoon
2	3	2	Tuesday and Wednesday aft.
3	3	2	Wednesday afternoon
1	3	2	Friday afternoon

Summary.-- A description has been given of the variables tested at defined levels and variables standardized in the experimentation. The general conditions during the tests and the conduct of experimentation including a time schedule have been outlined for complete information of the experimental procedure.

CHAPTER VI

ANALYSIS OF RESULTS

The analysis of the experimental results is broken down into four major parts. First, a necessary correction for an observed significant learning effect during experimentation is discussed. Second, a correlation is made between the scores on the battery of tests and the picking rate of the individual operators. Third and fourth, the experimental results are tested for the hypotheses outlined in Chapter III and are then statistically and graphically analyzed in order to determine density - belt speed combinations which will result in optimum picking rates and high quality of the pickouts.

In the analysis the two dependent variables were treated as the number of picked defective objects per minute and the per cent of good objects in the total pickouts. Because of the relatively small value of the products being picked and the high labor costs, the picking rate was based on the defective objects per minute rather than total objects per minute.

Correction for Learning Effect

It was pointed out earlier that, first, the subjects were unskilled in the picking operation and second, their time available for experimentation was limited. Due to a learning period of only twenty minutes for each operator prior to the experiments, a significant learning effect was reflected in the observed experimental data. The investigation was not designed to study the rate of learning of individual subjects in picking small objects but rather to treat in the analysis of the experimental data the variation between first and second replications as a random variable. It was necessary therefore to correct the observed data for the acquisition of skill during the experimentation.

An analysis of the learning curve of an individual subject from the results of only two replications is not possible, therefore it was decided to determine the average learning curve of all subjects tested. The randomization of the experimental conditions for each subject, i.e. the density - belt speed combination and the damage content of both replications, led to the assumption that by pooling the data, possible effects of individual learning rates in any tested experimental condition will be cancelled out. In Figure 4 the average number of picked defective objects per minute and in Figure 5 the average per cent of good objects in the total pickouts, both calculated from the test results of all nine operators, are plotted according to the sequence of the experimental runs. Polynomials, representing the average learning curves of the experimental subjects for hand quality picking, were fitted by the method of least squares. For equations and calculations see Appendix II. These theoretical curves were used to adjust the original data for the learning effect by using a horizontal line intersecting the theoretical curves between the eighth and ninth run. Corrections were applied to the original data (Tables 6 and 7, Appendix I) equal to the deviation of the theoretical curves from the horizontal lines. The corrected data were used for further analysis as recorded in Tables 8 and 9, Appendix I.

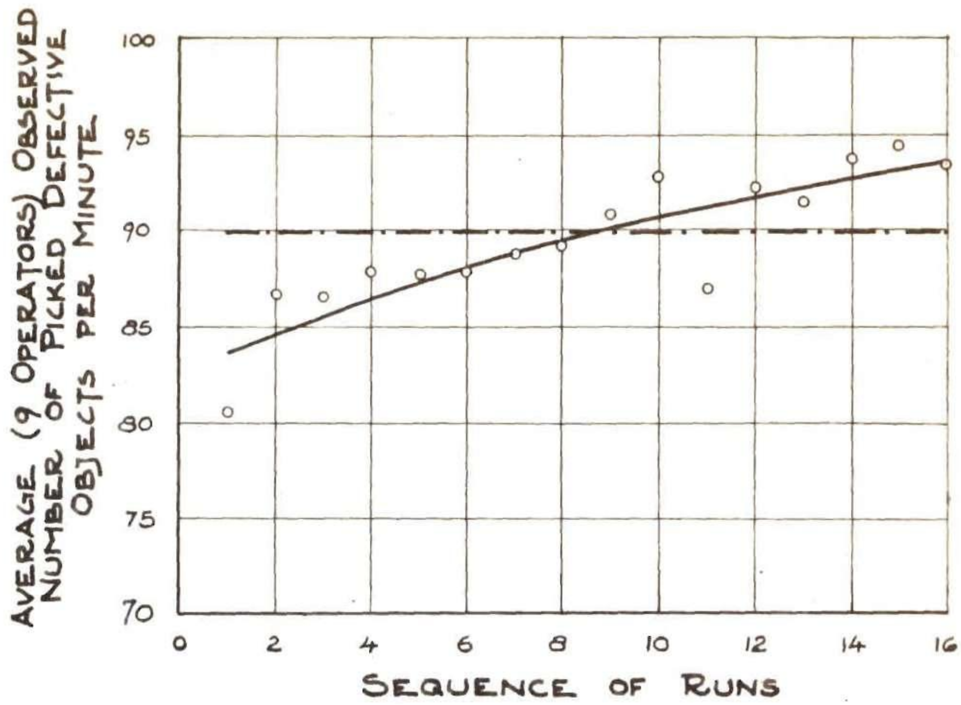

Figure 4. Observed Learning Curve in Picking Defective Objects

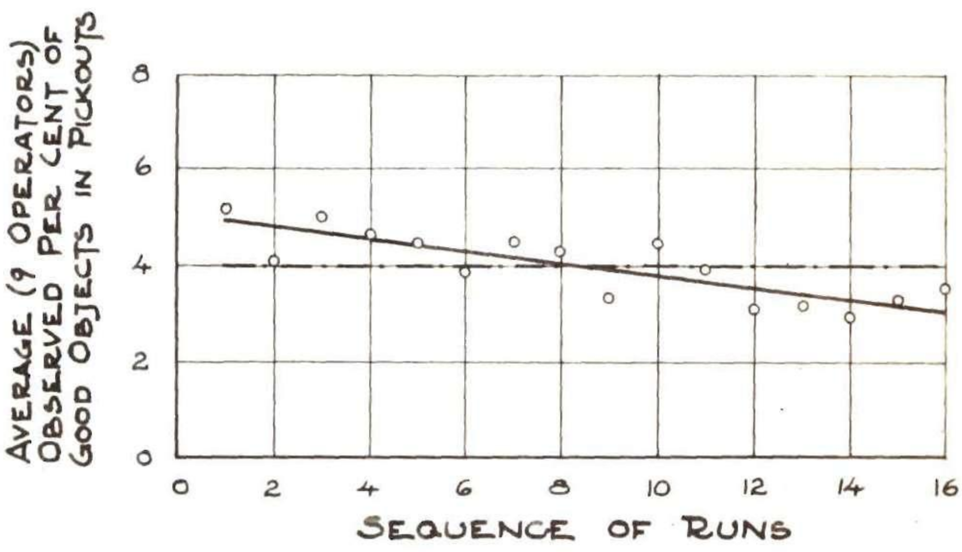

Figure 5. Observed Learning Curve in Picking Good Objects

Correlation Between Battery Test Score and Picking Rate

The second objective of the study is to determine whether or not an assumed relationship exists between the operators' picking rates and the scores on the battery of tests which were selected as described in Chapter IV.

The purpose of quality picking is to obtain a high rate of picked defective objects which include a minimum number of good objects. In Figure 6 a graphical presentation is given of the average corrected number of picked defective objects per minute (16 runs) versus the average score on the Purdue Pegboard Tests and the Moore Eye-Hand Coordination and Color-Matching Test. The scores on the dexterity tests are recorded in Table 5, Appendix I. As it was pointed out in Chapter IV, the battery test scores are dependent upon the subjects' passing the Bausch and Lomb vision test. A polynomial was fitted by the method of least squares and, in order to express how well the curve fits the plotted data, an index of the curve-linear correlation was calculated for each curve. An index of 1.0 represents perfect correlation and an index of zero indicates no relationship between the two variables studied. In Figure 6 the index of correlation is .877, a value which, when tested against a table of linear correlation coefficients, is significant at the .001 probability level. Expressed in other words, there is less than one chance out of a thousand that such a high index of correlation can be obtained when actually no correlation exists. Equations for computing the curvelinear correlation are given in Appendix II.

Curves were fitted and indices of correlation were calculated between five other combinations of the selected dexterity tests and the

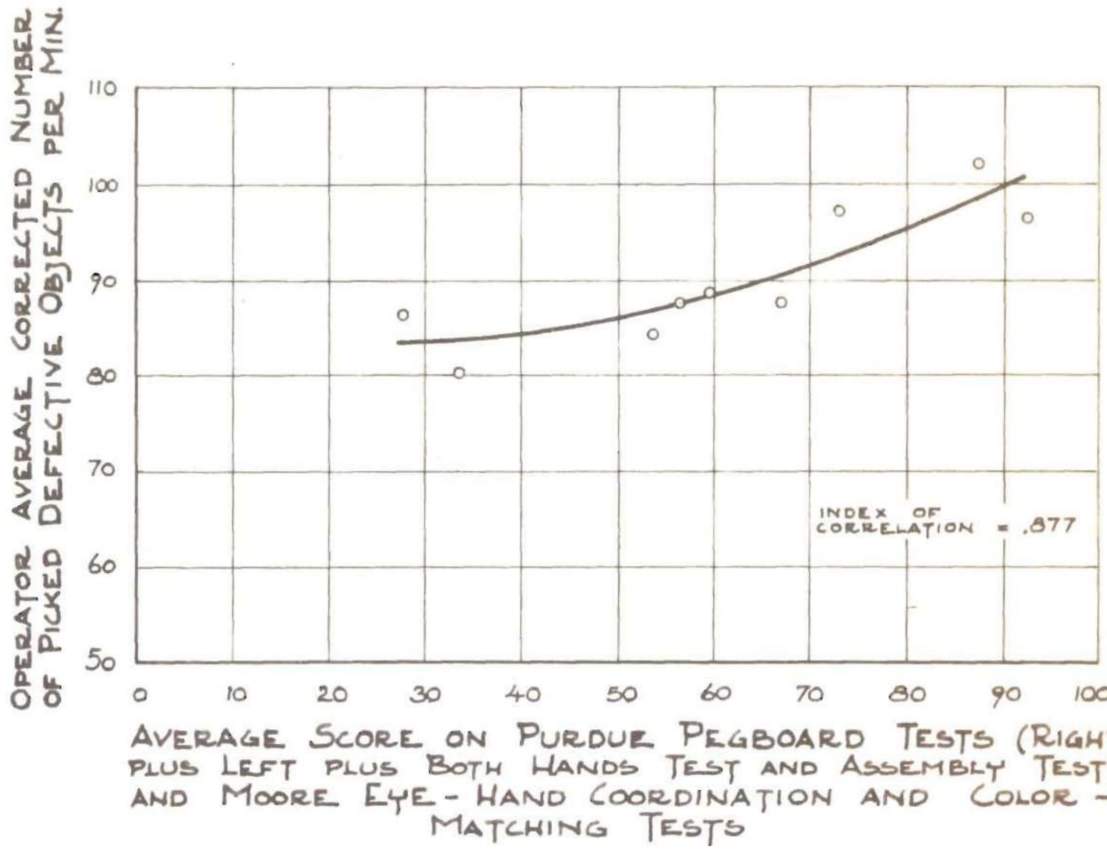

Figure 6. Average Picking Rate of Defective Objects per Operator versus Average Score on Purdue Pegboard Tests (Right plus Left plus Both Hands Test and Assembly Test) and Moore Eye-Hand Coordination and Color-Matching Tests

average number of picked defective objects per minute. The curves are presented in Appendix II. A summary of the results is given in Table 1. An index of correlation significant at the .02 probability level is denoted by one asterisk, at the .01 and the .001 probability levels by two and three asterisks, respectively. An average score of all the selected tests, the Purdue Pegboard Test (Right plus Left plus Both Hands Test and Assembly Test) and the Moore Eye-Hand Coordination and Color-Matching Test, gave the best results, however it was only slightly better than the score of the Purdue Pegboard, Assembly Test alone. It should be recalled, however, that the selection of the operators to participate in the dexterity tests was dependent upon their passing the Bausch and Lomb vision test according to the visual skill profile shown in Appendix I.

Statistical Analysis of Picking Rate

The statistical analysis is broken down according to the two *dependent* variables which were measured, the corrected number of picked defective objects per minute and the corrected per cent of good objects in the total pickouts. Each variable is discussed separately.

Corrected Number of Picked Defective Objects per Minute

The corrected number of picked defective objects per minute primarily determines the economy of hand quality picking of small objects. To determine the optimum conditions the null hypothesis was tested for the three hypotheses outlined in Chapter III. The analysis of variance was the statistical tool employed in testing the data (32).

Table 1. Indices of Correlation Between Test Batteries and Picking Rates of Defective Objects

Battery of Tests	Index of Correlation
Purdue Pegboard Test Average score on Right Hand Test, Left Hand Test and Both Hands Test Bausch and Lomb Visual Classification and Placement Test	.815 **
Purdue Pegboard Test Right plus Left plus Both Hands Test Bausch and Lomb Visual Classification and Placement Test	.810 **
Purdue Pegboard Test Assembly Test Bausch and Lomb Visual Classification and Placement Test	.856 **
Purdue Pegboard Test Average score on Right plus Left plus Both Hands Test and Assembly Test Bausch and Lomb Visual Classification and Placement Test	.844 **
Moore Eye-Hand Coordination and Color-Matching Test Bausch and Lomb Visual Classification and Placement Test	.754 *
Purdue Pegboard Test Right plus Left plus Both Hands Test and Assembly Test Moore Eye-Hand Coordination and Color-Matching Test Bausch and Lomb Visual Classification and Placement Test	.877 ***

* significant at the .02 probability level
** significant at the .01 probability level
*** significant at the .001 probability level

Note: Significance levels are from table of linear correlation coefficients.

An important assumption for the test of significance in the analysis of variance is that the error in the observations are from populations whose variances are homogenous. A check on the stability of the subjects was made by studying the ranges of the corrected experimental data from the two replications made by each subject on each set of experimental conditions (independent variables). Statistical control chart techniques (33) were employed to these ranges which showed excellent control at about the same variability for each subject. This technique offers sufficient assurance of the homogeneity of the experimental error variance, thereby satisfying this assumption underlying the analysis of variance.

The independent variables in the experiment were classified into Model I and Model II variables according to their effect upon the picking rate (34). Model I variables, the classes of grouped operators, the density - belt speed combinations and the damage contents of the lots, have a constant effect. Model II variables, the randomly selected operators within a class and the replications of the experiments under like conditions (corrected for learning effect), have a random variable effect. Model II variables allow a generalization of their effects upon the picking rate while the conclusions regarding Model I variables apply only to the fixed levels studied in the experiment. The model equation for the factorial experiment, analysis of variance tables, sample calculations and results of the analysis of variance are given in Appendix II. In Table 2 only those factors are presented which have a significant effect upon the picking rate and are denoted by three probability levels. One asterisk indicates that the factor is significant at the .05 probability

Table 2. Significant Factors Influencing the Picking of Defective Objects

Factor	Degree of Freedom	Mean Square
Class	2	265,187 **
Operator	6	17,671 *
Density - Belt Speed	3	131,730 ***
Damage Content	1	163,216 ***
Operator x Density - Belt Speed	18	2,521 *
Damage Content x Density - Belt Speed	3	4,145 *
Residual	72	1,593

* significant at the .05 probability level
** significant at the .01 probability level
*** significant at the .001 probability level

level. Two and three asterisks denote a significance level of .01 and .001, respectively. The results of the analysis of variance, as indicated in this table, reject the three hypotheses stated in the objectives of the experiments.

Table 3 expresses the significant main effects and interactions as a per cent of the grand average of all operators of the corrected number of picked defective objects per minute. The grand average was 90.1 pickouts. The discussion below is in terms of these percentages. Both the main effects and the interactions follow in the order of decreasing importance.

Density - Belt Speed.-- This variable had the greatest effect on the hand quality picking operation. The second level, with a density of 25 per cent and a belt speed of 40 feet per minute, was always found to be the most favorable level of all four combinations tested in the experiment at the investigated constant rate of flow. This level resulted in a 14.5 per cent higher picking rate than the first combination and in a 5.4 per cent and a 7.5 per cent higher rate than the third and fourth combinations, respectively. Due to the confounded effect of density, however, it is not possible to say from these experiments whether a change in the belt speed or a change of the density had the greater effect upon the picking rate.

Based upon the findings cited above by Moder that belt speeds between 10 and 60 feet per minute did not appreciably affect the picking rate, and Calhoun's results that more pickouts were obtained at his lowest investigated density of 33 per cent, it can be assumed that

Table 3. Significant Main Effects and Interactions Expressed as a Per Cent of the Grand Average of all Operators of the Corrected Number of Picked Defective Objects per Minute

Class	Operator	Operator	Class	Density - Belt Speed Combination 1	2	3	4	Damage Content 1	2
1	1	113.3	109.6	108.3	118.6	117.9	108.5	-	-
	2	108.0		101.1	115.1	111.5	104.3	-	-
	3	107.2		103.4	116.0	109.5	99.9	-	-
2	1	98.4	94.8	89.0	109.0	99.7	95.9	-	-
	2	97.6		91.6	107.5	101.2	88.1	-	-
	3	89.0		81.9	95.4	92.5	86.3	-	-
3	1	93.5	95.6	84.8	101.4	95.9	91.9	-	-
	2	97.5		96.4	106.6	97.7	89.3	-	-
	3	95.5		87.0	103.8	99.0	93.4	-	-
Average		100.0		93.7	108.2	102.8	95.3	96.3	103.7
Damage	1	-	-	91.5	104.8	98.3	90.4	-	-
	2	-	-	96.0	111.5	107.2	100.2	-	-

Grand Average of all operators = 90.1 picked defective objects per minute
- indicates factor is not significant

the density of the objects on the belt is the most critical factor influencing the picking rate. A high number of the pickouts for a low density level might be explained as follows: Wide spacing of the objects on the belt relative to each other is more favorable to a high picking rate than close spacing. The reason for this is that the operator can grasp an object better when there is no interference from other objects. Presumably, at a constant belt speed there is a certain density below which no appreciable increase of the picking rate can be obtained. This density is assumed to give just enough space to the fingers in order to accurately grasp an object. Because the spacing of the objects is a function of both density and belt speed it is assumed that for different rate of flows of objects on the belt there exists a certain range of optimum density - belt speed combinations.

Damage Content.-- The high damage content consistently resulted in more pickouts than the low damage content for all tested operating conditions. The difference between high and low damage content was, on the average, 7.4 per cent. These results substantiate the findings of previous studies which found that the operator spends less time searching for a defective object when a greater number of such objects are presented to him.

Class.-- The difference between the per cent picked defective objects of class 1 and the average per cent of class 2 and 3 was 14.4 per cent. The marked difference proves the applicability of the selected battery of tests in distinguishing good quality pickers from average pickers. However, it was not possible to successfully separate class 2 operators from class 3 operators.

An economical consideration of the effect of per cent good ob-

Operators.-- Significance of the operators at the .05 probability level shows that differences existed between the operators within a class. The range of these differences was 6.1 per cent for class 1, 9.4 per cent for class 2, and 4.0 per cent for class 3, with an average of 6.5 per cent. A maximum difference of 19.8 per cent between the best subject and the least successful subject proves again that the test battery can discriminate almost exactly between good and average operators.

Operator x Density - Belt Speed.-- All the operators had their best picking rate at the second density - belt speed level, followed by the third level as the next best combination. For the first and fourth level, however, there were significant differences in the picking rates of the operators. Six operators favored the fourth level and three operators the first level as their third best density - belt speed combination.

Damage Content x Density - Belt Speed.-- This interaction indicates that different combinations of damage contents and density - belt speed levels had significantly different effects upon the picking rate. The analysis of the data revealed that the difference in per cent increase of the pickouts between the low damage content and the high damage content was in an ascending order of the density - belt speed combinations. Expressed in other words, this difference due to damage content became greater with increasing belt speed and decreasing density levels.

Corrected Per Cent of Good Objects in Pickouts

An economical consideration of the effect of per cent good objects in the total pickouts upon the costs of the hand quality picking operation in the peanut processing industry led to the conclusion that this effect is so small as to be negligible. The loss of value of the product by placing good objects in the pickouts amounted to $ 0.10 per operator per 8 hour working day. This figure, however, does not make allowances for the time lost in this operation, however, this is not necessary since the good objects were not considered in the picking rate analysis (See Appendix III for the economy study). It was regarded to be satisfactory, therefore, to present and discuss the experimental data in their relative magnitude as a per cent value of the grand average corrected per cent of good objects in the pickouts. These per cent values are shown in Table 4. It should be emphasized that the values are relative terms based on the grand average corrected per cent of good objects in the pickouts of all operators of only 4.0 per cent. It would be misleading, therefore, to regard the data as actual per cent of the total pickouts.

In the following the experimental factors are discussed individually in order of their decreasing importance upon the picking quality:

Operator.-- The largest difference in the per cent of good objects in the pickouts was found to be present between the individual operators. This difference based upon the average per cent of good objects in the pickouts was as great as 165.7 per cent between the operator having the lowest picking quality and the one having the highest quality. In each class there was one operator with an extreme value for his picking quality: One operator in class 1 and 2 showed a very low quality of his pickouts and in class 3 one operator picked an extremely good

Table 4. Experimental Factors Expressed as a Per Cent of the Grand Average Corrected Per Cent of Good Objects in the Pickouts

Class	Operator	Operator	Class 1	Class 2	Class 3	Density - Belt Speed Combination 1	2	3	4	Damage Content 1	2
1	1	153.3	110.8			137.2	117.3	228.9	129.7	179.6	126.9
	2	93.7				63.6	66.1	139.1	106.0	109.4	77.9
	3	85.5				103.5	69.2	101.7	67.4	100.0	68.9
2	1	183.4		124.3		133.5	134.1	203.3	263.2	195.2	171.8
	2	92.0				71.7	87.3	88.6	120.4	93.8	90.1
	3	97.6				100.4	53.6	109.8	126.6	99.8	95.4
3	1	17.7			64.9	11.8	9.4	20.6	29.3	18.4	17.1
	2	80.2				104.8	68.6	46.8	100.4	86.1	74.2
	3	96.6				91.1	55.5	126.6	112.9	99.7	93.6
Average		100.0				90.9	73.4	118.4	117.3	109.3	90.7
Damage Content	1	109.3	130.4	129.6	68.0	107.8	77.8	137.8	114.3		
	2	90.7	91.2	119.2	61.6	74.1	69.1	99.3	120.6		
Density-Belt Speed Comb.	1	90.9	101.4	101.9	69.2						
	2	73.4	84.2	91.7	44.5						
	3	118.4	156.5	134.0	64.7						
	4	117.3	101.0	170.1	80.8						

Grand Average of all operators = 4.0 per cent good objects in pickouts quality. This fact cautions against drawing valid conclusions as to which class of operators had the highest picking quality.

Density - Belt Speed.-- The operators showed their highest picking qualities at different density - belt speed combinations. However, it can be generalized that the second density - belt speed combination resulted in a higher picking quality than the first, the fourth, and the third combinations, listed in descending order of their influence upon the quality of the pickouts. The difference between the second combination, the most favorable, and the third combination, the most unfavorable, was 45 per cent based upon the grand average per cent of good objects in the total pickouts.

Damage Content.-- Generally, the high damage content resulted in an improved picking quality. The grand average difference between the low damage level and the high damage level was 18.6 per cent. The three classes of operators reacted differently to a change in the damage content. Based upon the grand average per cent of good objects in the pickouts class 1 had a difference of 39.2 per cent between the low damage content and the high damage content while class 2 and 3 had differences of 10.4 per cent and 6.4 per cent, respectively.

Graphical Analysis of Picking Rate

The graphical presentation of the results is given for two reasons. First, an interpretation of optimum operating conditions is simplified by interpolating the picking curves. Second, a graphical presentation shows more obviously fluctuations in the output curves.

Figures 7 and 8 show graphs for each damage content presenting the corrected number of picked defective objects per minute of the three classes in relation to the density - belt speed combinations. It is very noticable how well the test battery differentiated between the operators of class 1 and the operators of class 2 and 3 combined. The shaded column designates an optimum range of density - belt speed combinations of all operators for the investigated rate of flow. The range was derived from the individual picking rates of defective objects per operator and per damage content as shown in Figures 20 through 22, Appendix III. The range of optimum density and belt speed combinations was recorded for each curve in Table 15. This range designates all density - belt speed combinations of both damage levels at which the operators' picking rates varied within one defective object from their maximum number of picked defective objects. In this table the overlapping densities and belt speeds indicate that the optimum range for all operators for the investigated rate of flow was between 20.8 and 21.8 per cent density and between a belt speed of 46 and 48 feet per minute.

The attempt was made to establish in the same manner a range of density - belt speed combinations for both damage levels at which the operators' pickouts varied within one per cent from their minimum per cent of picked good objects. However, because of the wide differences between some individual operators, it was not possible to find overlapping ranges which would indicate that an optimum range for all operators was present (See Table 16). Figures 23 through 25 in the Appendix III show the different fluctuations of the curves representing

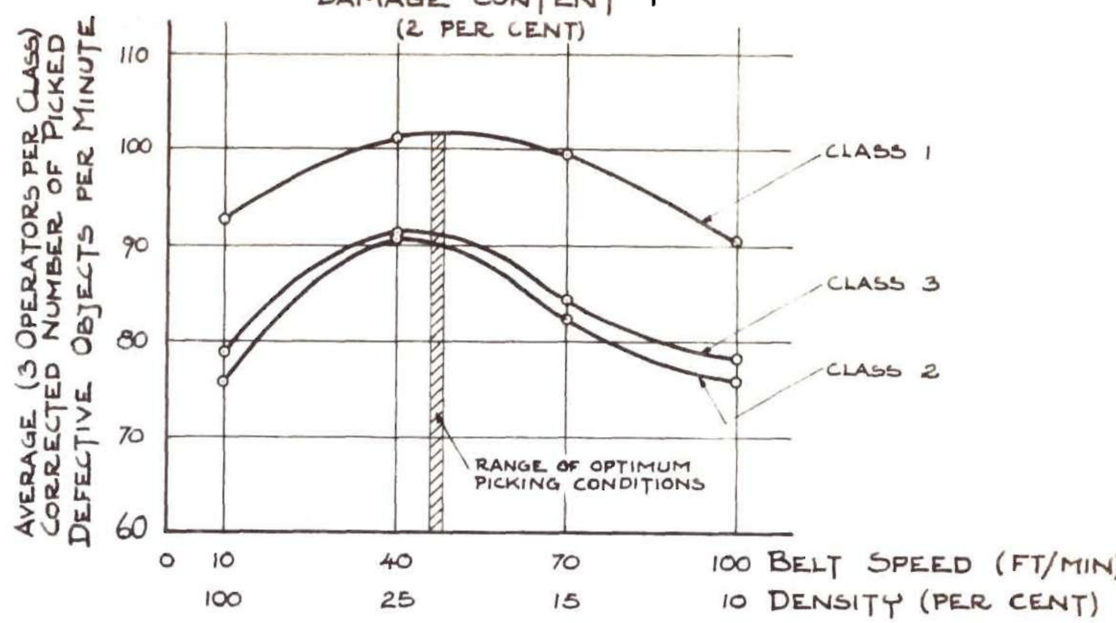

Figure 7. Average Picking Rate of Defective Objects versus Density - Belt Speed Combinations for Operator Classes and Low Damage Content

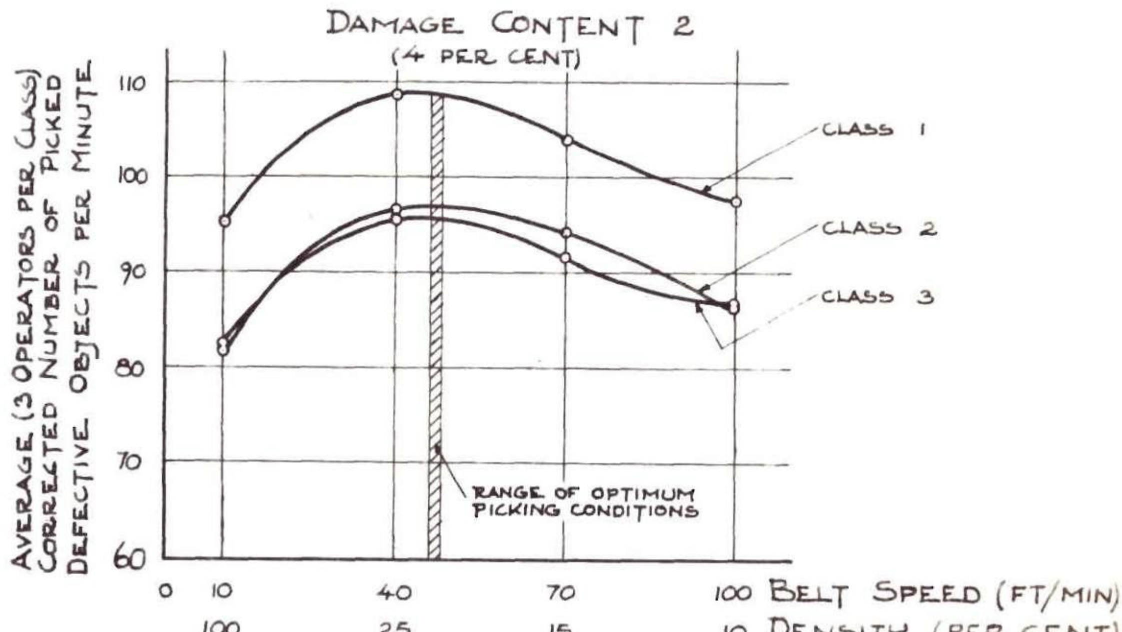

Figure 8. Average Picking Rate of Defective Objects versus Density - Belt Speed Combinations for Operator Classes and High Damage Content

the operators' picking quality. Combined curves for the three classes of operators are given in Figures 9 and 10. These figures indicate that at the low damage content level, a definite minimum range, i.e. high picking quality, can be observed which occurs between a density of about 22.2 and 27.4 per cent and a belt speed between 34 and 42 feet per minute. For the high damage level the results are about the same, however, not so well defined.

An overall survey of the experimental data can be gained by reference to the pooled curves in Figures 11 and 12. The curves for the grand average corrected number of picked defective objects per minute for indicated density - belt speed combinations are shown in Figure 11 while the curves for grand average per cent of good objects in the pick-outs are presented in Figure 12. It was mentioned earlier that the effect of the picking quality upon the costs of the picking operation is practically negligible. The most favorable range of density - belt speed combinations for a high quality in picking was clearly below that favoring a high number of picked defective objects per minute. It can therefore be concluded that for the investigated experimental conditions the lower level of the established favorable range for a high rate of picked objects resulted in optimum hand quality picking conditions for all operators at both damage contents. This optimum level was at a density of 21.8 per cent and a belt speed of 46 feet per minute.

Summary.-- A detailed analysis of the experimental data was given in this chapter. The correction for an observed significant learning effect of the operators during experimentation was discussed and the correlation

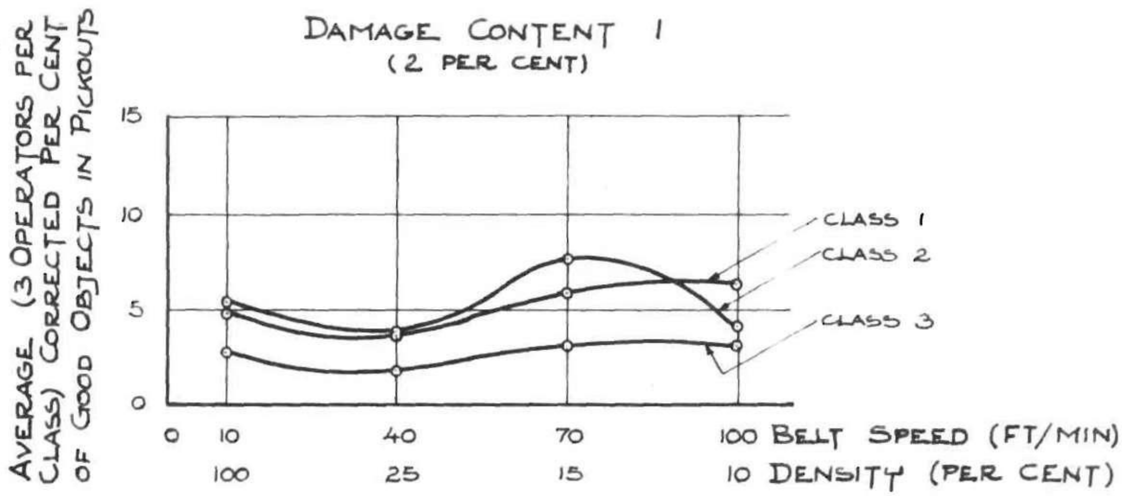

Figure 9. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Operator Classes and Low Damage Content

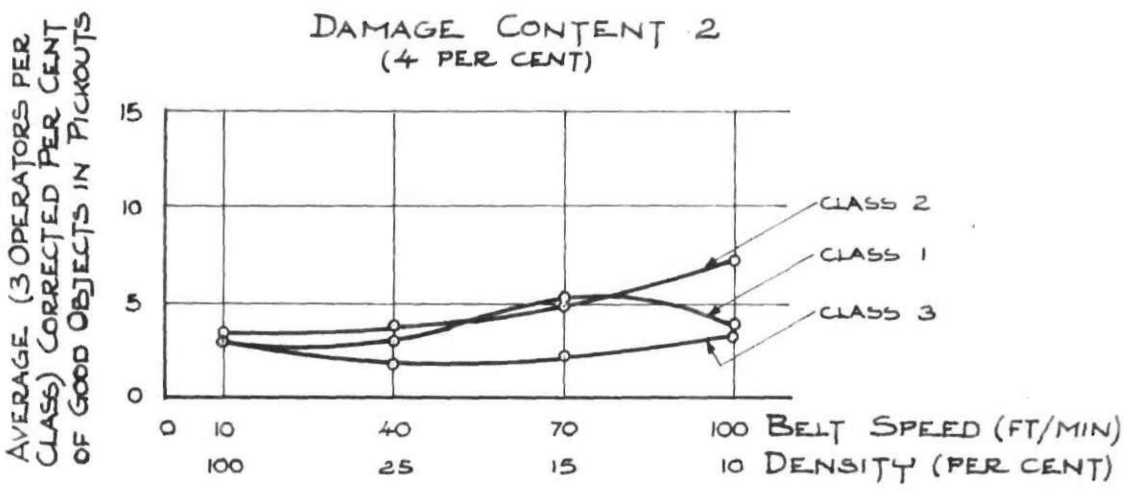

Figure 10. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Operator Classes and High Damage Content

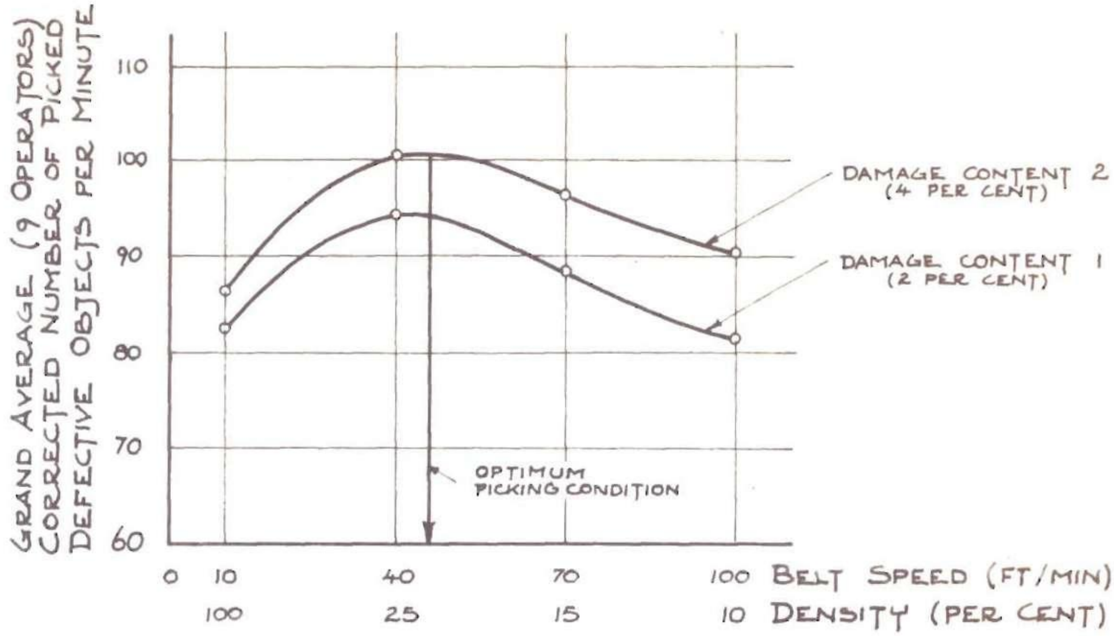

Figure 11. Grand Average Picking Rate of Defective Objects versus Density - Belt Speed Combinations for Damage Contents

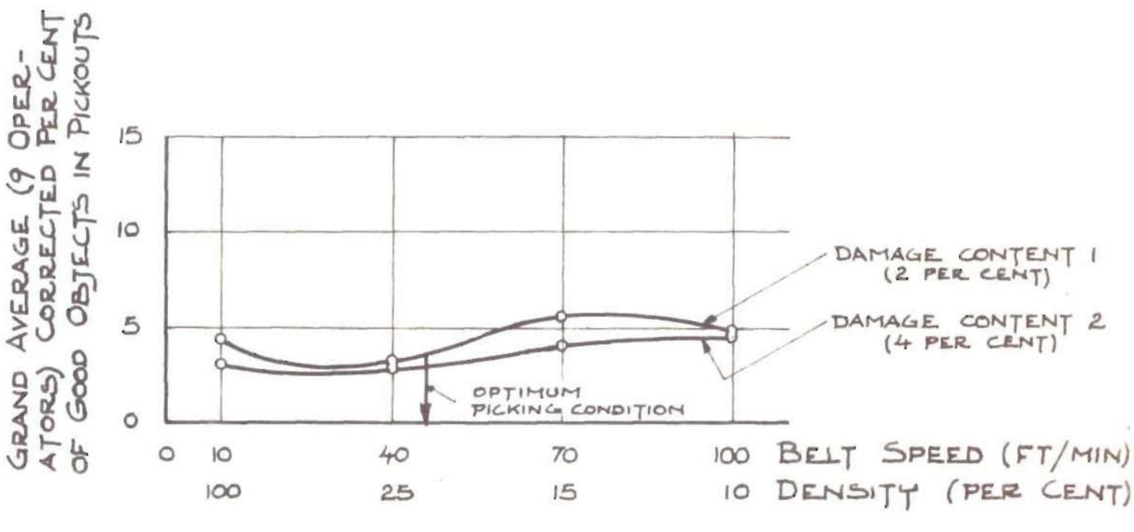

Figure 12. Grand Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Damage Contents

between battery test scores and picking rates was calculated. By means of statistical and graphical analyses of the experimental data optimum picking conditions were established and the effect which each investigated independent variable had upon the rate of picking was determined. In the following chapter the limitations and conclusions of the study were summarized and recommendations are given to problems which were raised during this study and which require further investigation beyond the limits of this study.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations to be discussed are based only upon the experimental results of this study which entails the following limitations:

1. The experimental subjects were:

    a. Male college students rather than female factory workers for whom the study should be intended,

    b. Unskilled operators with a limited time available for training in hand quality picking which resulted in a significant learning effect,

    c. Highly motivated because of the experimental nature of the study.

2. Great Northern beans used as experimental objects in this study might not be representative of all small objects that require hand quality picking in industry.

3. The investigation of each experimental condition was limited to only two replications.

4. Only one rate of flow of objects was tested.

Conclusions.-- In view of the above limitations and the results of the experiments the following conclusions may be drawn:

1. The first objective of this thesis, to select tests which discriminate between the aptitude characteristics of successful and unsuccessful hand quality pickers, has been accomplished. The test battery consisted of two dexterity tests and one visual skill test; they were:

    a. The Purdue Pegboard Test, Right plus Left plus Both Hands Test and Assembly Test,

b. The Moore Eye-Hand Coordination and Color-Matching Test (color-matching only),

c. The Bausch and Lomb Visual Classification and Placement Test.

The battery of tests discriminated between good operators (class 1, upper quartile) and average operators (class 2 and 3, middle quartiles) whose average picking rates of defective objects differentiated by 14.4 per cent based upon the grand average picking rate of all operators. A discrimination between class 2 and class 3 operators according to their picking rates was not possible.

2. The second objective was to determine an index of correlation between the scores on the battery of tests and the operators' picking rates of defective objects. This index of correlation was found to be .877, an index which is significant at the .001 probability level of linear correlation coefficients.

3. The final objective was to develop density - belt speed combinations which result in optimum picking rates and high picking quality. The following conclusions were drawn:

   a. A density of 22 per cent and a belt speed of 46 feet per minute resulted in optimum picking rates of defective objects and a high picking quality for all operators and both damage contents tested. An optimum picking rate was defined to encompass all rates within one defective object per minute of the operators' maximum number of picked defective objects per minute.

   b. A greater drop in the picking rate of defective objects at both levels of damage contents was observed for belt speeds below the optimum value or densities above the optimum value.

   c. A greater drop in the picking quality at both levels of damage contents was observed for belt speeds above the optimum value or densities below the optimum value.

4. Another important point noted in the results was:

   The high damage content consistently resulted in higher picking rates of defective objects and better picking quality than the low damage content.

Recommendations.-- With regard to the previously mentioned limitations and conclusions the following recommendations may be made leading to further refinement of hand quality picking of small objects:

1. The effects of density and belt speed upon the picking rate and picking quality should be studied for different rates of flow, particularly higher rates.

2. The devised battery of tests should be validated by selecting experienced female operators for experimental subjects and correlating their test scores and their picking rates.

3. The learning effect should be minimized in the experimental data by including a sufficient number of replications under like operating conditions so that the subjects' learning curves are stabilized.

4. Experimentation should be extended to the use of other objects besides Great Northern beans.

5. The effect of the width of the conveyor belt upon the picking rate and picking quality should be studied, particularly for smaller belt widths than were used in this study.

APPENDIX I

EXPERIMENTAL DATA

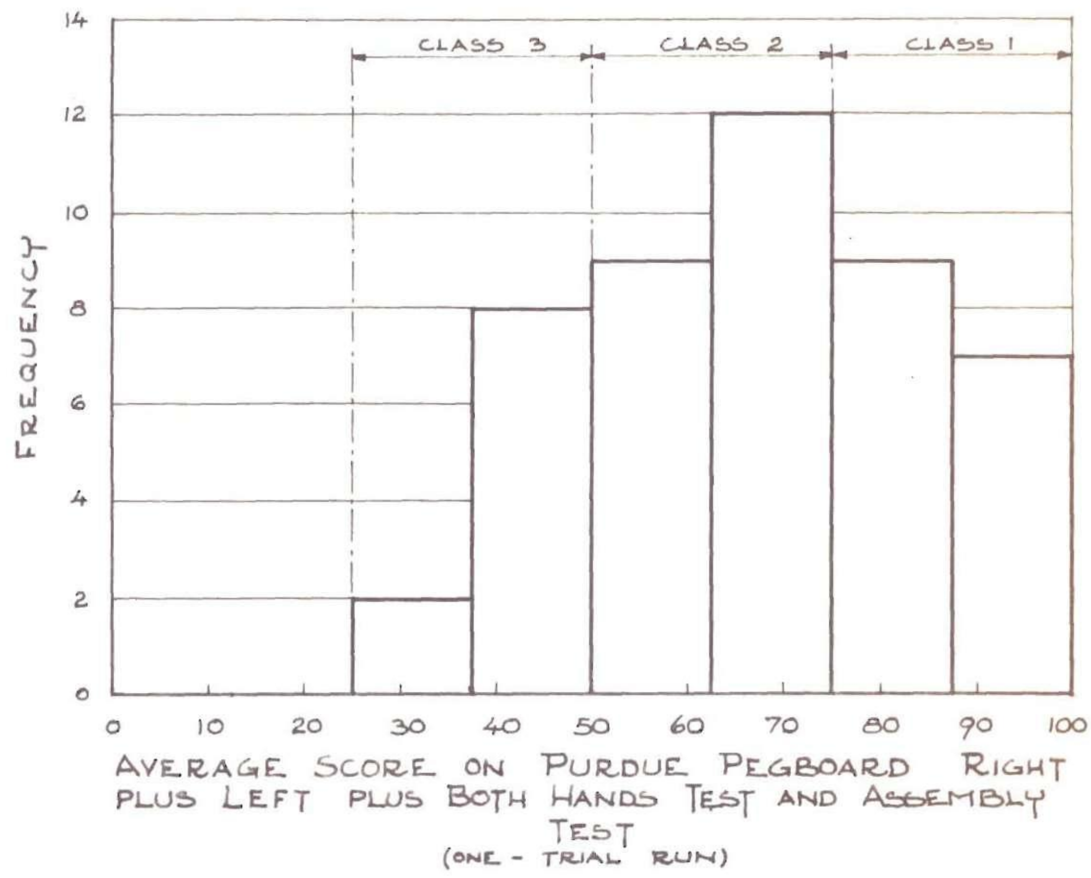

Figure 13. Histogram of Average Scores of 47 Male Subjects on Purdue Pegboard Right plus Left plus Both Hands Test and Assembly Test (One-trial run)

Visual Skill Test

The visual profile for hand quality picking small objects as shown in Figure 14 is marked by the blank areas in the chart. It was derived from the visual profiles for inspection and machine work which were recommended by the Bausch and Lomb Optical Company.

The blank areas define the vision which a good hand quality picker should have, while the hatched and cross-hatched areas show the scores which an operator, in order to be selected for quality picking, should possibly not have and cannot have, respectively.

A requirement for the selection of the subjects for experimentation was a passing score on this visual skill test performed with the Ortho - Rater*, i.e. the subjects' scores had to fall within the blank area of the chart. An example was given in Figure 14 of the visual performance profile of operator 1 in class 1.

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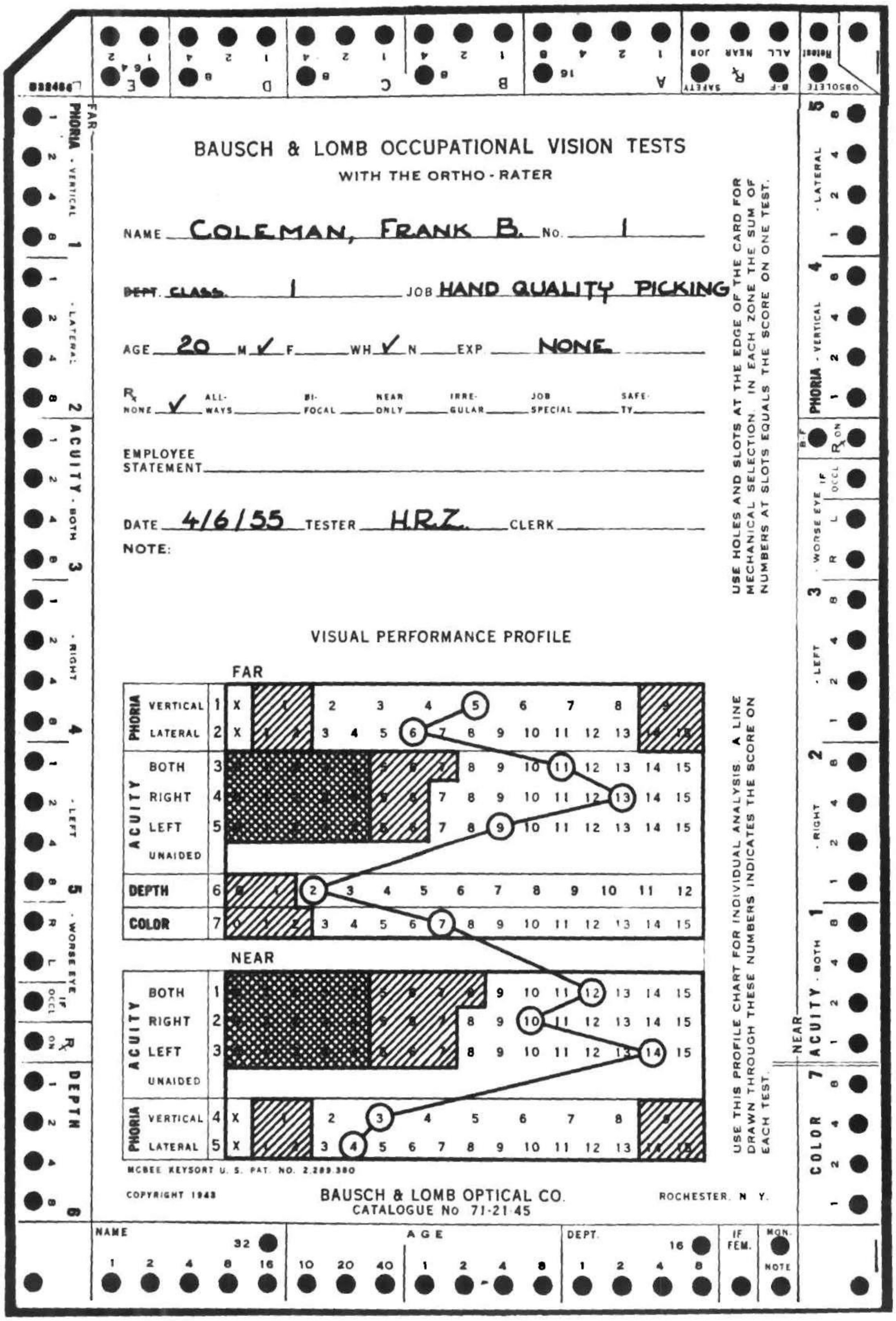
*Ortho - Rater manufactured by the Bausch and Lomb Optical Company, Rochester, N.Y.



BAUSCH & LOMB OCCUPATIONAL VISION TESTS
WITH THE ORTHO-RATER

NAME COLEMAN, FRANK B. NO. 1

~~DEPT.~~ CLASS. 1 JOB HAND QUALITY PICKING

AGE 20 M ✓ F __ WH ✓ N __ EXP. NONE

R_x NONE ✓ ALL-WAYS __ BI-FOCAL __ NEAR ONLY __ IRREGULAR __ JOB SPECIAL __ SAFETY __

EMPLOYEE STATEMENT

DATE 4/6/55 TESTER H.R.Z. CLERK

NOTE:

USE HOLES AND SLOTS AT THE EDGE OF THE CARD FOR MECHANICAL SELECTION. IN EACH ZONE THE SUM OF NUMBERS AT SLOTS EQUALS THE SCORE ON ONE TEST.

VISUAL PERFORMANCE PROFILE

FAR

PHORIA	VERTICAL	1	X 1 2 3 4 5 6 7 8 9
	LATERAL	2	X 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
ACUITY	BOTH	3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
	RIGHT	4	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
	LEFT	5	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
	UNAIDED		
DEPTH		6	0 1 2 3 4 5 6 7 8 9 10 11 12
COLOR		7	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

NEAR

ACUITY	BOTH	1	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
	RIGHT	2	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
	LEFT	3	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
	UNAIDED		
PHORIA	VERTICAL	4	X 1 2 3 4 5 6 7 8 9
	LATERAL	5	X 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

USE THIS PROFILE CHART FOR INDIVIDUAL ANALYSIS. A LINE DRAWN THROUGH THESE NUMBERS INDICATES THE SCORE ON EACH TEST.

MCBEE KEYSORT U. S. PAT. NO. 2,289,380

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CATALOGUE No 71-21-45

Figure 14. Visual Skill Profile for Hand Quality Picking Small Objects

Table 5. Scores on Battery of Tests

Class	Operator	Test Number	Purdue Pegboard Right Hand Test	Purdue Pegboard Left Hand Test	Purdue Pegboard Both Hands Test	Purdue Pegboard R.+L.+ B. H. Test	Assembly Test	Moore Eye - Hand Coord. and Color-Match. Test	Bausch and Lomb Vis. Class. and Placement Test
1	1	1	67	80	79	74	100	85	OK
		2	86	80	70	78	98	90	
	2	1	47	92	79	74	90	55	OK
		2	79	92	93	90	90	65	
	3	1	67	80	98	87	100	80	OK
		2	95	98	93	96	100	99	
2	1	1	67	62	55	55	59	40	OK
		2	30	62	79	45	78	80	
	2	1	67	42	68	50	86	40	OK
		2	86	62	68	70	89	80	
	3	1	67	62	55	55	59	1	OK
		2	47	80	30	45	76	15	
3	1	1	30	62	30	30	45	70	OK
		2	86*	40*	78*	60*	75*	70*	
	2	1	30	42	55	30	45	70	OK
		2	67	42	87	60	66	55	
	3	1	2	42	55	12	38	5	OK
		2	67	21	70	43	66	25	

* Operator lifted weights at the time of the first series of aptitude tests and during experimentation. At the time when the second test series was given the operator was temporary inactive in weight lifting which was noted in consistently higher density test scores. The scores on the second test series were omitted in computing the average test scores of this operator because of the higher dexterity which was not present during experimentation.

Legend to Tables 6 Through 9

C1	Class 1
C2	Class 2
C3	Class 3
O1	Operator 1
O2	Operator 2
O3	Operator 3
S1	Density - Belt Speed Combination 1
S2	Density - Belt Speed Combination 2
S3	Density - Belt Speed Combination 3
S4	Density - Belt Speed Combination 4
D1	Damage Content 1
D2	Damage Content 2
R1	Replication 1
R2	Replication 2

Table 6. Observed Number of Picked Defective Objects Per Minute Based on a Four Minute Test Run

			C1			C2			C3		
			O1	O2	O3	O1	O2	O3	O1	O2	O3
R1	S1	D1	92.25	88.25	84.25	75.00	80.75	63.75	73.00	82.25	74.75
		D2	100.75	85.75	90.25	82.50	85.50	75.75	79.75	89.50	71.75
	S2	D1	100.50	97.00	92.00	91.00	91.50	80.50	89.25	88.00	91.50
		D2	100.50	107.50	104.50	100.75	96.50	83.75	87.25	101.75	91.00
	S3	D1	103.00	88.50	91.75	71.25	86.75	76.75	83.00	82.75	85.75
		D2	100.75	98.00	95.50	94.25	93.75	83.50	90.75	81.75	94.00
	S4	D1	87.25	89.75	71.50	77.50	74.00	72.00	73.75	78.75	75.00
		D2	94.25	92.75	87.25	88.25	83.75	82.00	86.25	85.00	81.75
R2	S1	D1	101.75	99.00	95.00	76.25	74.00	72.50	73.25	82.75	78.75
		D2	98.00	95.50	100.00	81.50	82.00	74.25	76.50	88.75	85.00
	S2	D1	105.75	101.00	102.75	97.25	98.50	83.50	91.00	93.25	92.00
		D2	112.50	103.00	116.50	105.00	106.25	86.75	92.00	98.25	96.75
	S3	D1	108.75	103.00	99.00	86.00	81.50	79.00	85.00	84.50	86.50
		D2	110.50	107.75	110.50	98.75	96.25	86.25	92.50	98.50	94.75
	S4	D1	103.00	92.75	93.25	85.25	74.25	70.75	77.75	77.00	84.25
		D2	104.25	100.00	103.50	100.25	86.75	85.25	89.25	85.25	91.25

Table 7. Observed Number of Picked Good Objects Per Minute Based on a Four Minute Test Run

			C1			C2			C3		
			O1	O2	O3	O1	O2	O3	O1	O2	O3
R1	S1	D1	9.50	3.75	2.25	5.50	3.75	5.50	.50	4.75	1.50
		D2	6.25	1.75	1.75	4.25	3.50	3.50	1.00	3.75	2.50
	S2	D1	7.00	5.25	2.75	5.50	3.25	1.00	.25	3.50	2.50
		D2	6.75	4.25	1.25	5.50	2.75	1.00	.75	2.50	2.50
	S3	D1	9.50	12.00	3.25	8.25	6.50	4.25	.75	2.75	5.50
		D2	7.75	6.75	3.50	6.75	4.00	6.00	.25	1.00	3.75
	S4	D1	7.25	6.50	2.00	6.75	4.50	3.25	2.25	4.00	3.75
		D2	7.75	3.75	1.25	12.50	8.00	4.00	1.25	4.50	4.50
R2	S1	D1	4.25	.75	11.00	4.75	1.25	2.75	.25	3.0	4.25
		D2	1.75	2.00	2.00	3.75	2.00	1.00	0	3.75	3.75
	S2	D1	6.00	1.25	2.75	5.25	3.25	1.00	.50	2.75	1.25
		D2	1.75	1.50	5.25	5.00	3.25	3.25	.25	2.25	2.50
	S3	D1	15.50	2.50	6.50	7.00	2.25	3.25	0	1.00	5.50
		D2	10.25	1.75	3.00	10.00	1.25	2.50	.50	2.00	3.25
	S4	D1	3.50	2.50	1.75	12.50	1.25	3.25	0	2.00	3.25
		D2	2.25	3.50	5.50	8.0	2.25	5.00	.50	2.25	4.50

Table 8. Corrected and Coded Number of Picked Defective Objects per Minute
(Corrected Number of Picked Defective Objects per Minute + 800) x 0.1

			C1			C2			C3		
			O1	O2	O3	O1	O2	O3	O1	O2	O3
R1	S1	D1	140	85	60	-8	60	-100	-45	65	10
		D2	232	68	128	60	118	10	15	130	-30
	S2	D1	258	212	155	128	125	15	145	105	132
		D2	268	310	288	232	168	55	135	235	135
	S3	D1	232	148	128	-25	102	2	32	80	68
		D2	218	232	158	195	180	78	118	80	142
	S4	D1	115	122	-22	-22	-42	-55	-20	-10	-15
		D2	178	145	125	92	62	0	98	60	60
R2	S1	D1	182	160	140	-40	-75	-90	-70	12	-45
		D2	148	130	198	-5	0	-68	-45	68	15
	S2	D1	242	200	202	148	152	70	80	122	110
		D2	305	228	335	220	228	100	95	180	165
	S3	D1	298	195	175	45	12	-12	15	12	40
		D2	302	245	285	178	152	65	92	150	118
	S4	D1	200	112	98	18	-82	-62	-38	-60	22
		D2	218	180	202	170	38	28	72	28	98

De-coded grand average = 90.1 picked defective objects per minute

Table 9. Corrected Per Cent of Good Objects in Total Pickouts

			C1			C2			C3		
			01	02	03	01	02	03	01	02	03
R1	S1	D1	9.1	4.1	2.4	6.1	3.6	6.9	.3	4.8	1.0
		D2	5.4	1.9	1.5	4.4	2.9	3.6	1.0	3.5	2.6
	S2	D1	5.7	4.4	2.4	5.5	3.3	1.1	-.5*	3.4	2.5
		D2	5.3	3.3	.5	4.8	2.8	1.0	-.1*	2.2	2.3
	S3	D1	8.4	11.0	3.3	9.4	6.5	4.7	.9	2.4	5.9
		D2	7.0	5.6	3.5	5.9	3.4	6.0	.2	.2	3.8
	S4	D1	7.0	6.4	1.7	8.0	5.5	3.9	2.3	4.8	4.3
		D2	7.1	3.7	.6	12.3	8.3	5.2	.9	4.9	4.5
R2	S1	D1	4.9	1.5	10.6	6.0	2.1	4.1	.4	3.9	5.9
		D2	2.6	2.7	2.1	4.9	2.9	1.5	.2	4.6	5.1
	S2	D1	5.8	1.4	3.2	6.0	4.0	2.1	1.2	3.1	1.5
		D2	2.0	1.5	5.0	5.2	3.9	4.4	.9	2.3	2.6
	S3	D1	12.7	3.3	6.4	7.9	2.8	4.1	.9	2.0	6.6
		D2	8.6	2.4	3.1	9.4	1.5	2.8	1.3	2.9	4.0
	S4	D1	4.0	3.0	2.7	13.7	2.3	5.1	.4	3.2	4.2
		D2	2.7	3.9	5.8	8.2	3.2	6.1	1.1	3.2	5.1

* Actual per cent of good objects in pickouts became negative after correcting the value by the average learning effect. For consistency in calculation the value was not accepted as zero.

Grand average = 4.00 per cent good objects in pickouts

APPENDIX II

STATISTICAL ANALYSIS

AND SAMPLE CALCULATIONS

Calculation of Learning Curve

In the following the calculation of the learning curve is shown for the picking rates of defective objects. Similar calculations were made for the curve indicating the learning effect in the picking quality.

According to the sequence of the runs of each operator the observed numbers of picked defective objects per minute were pooled and averaged, i.e. divided by 9, the number of operators. These average values were coded for all 16 experimental runs by subtracting 80 pickouts per minute from each reading and were recorded as "y" values in Table 10. The sequence of each run was coded by subtracting 8 and was recorded as "x" values. After performing the computations indicated in Table 10, the results were substituted in the normal equations for the least squares, curve fitting given below (35):

$$(1) \qquad 16\,a + 8\,b + 344\,c = 151.40$$

$$(2) \qquad 8\,a + 344\,b + 512\,c = 300.12$$

$$(3) \qquad 344\,a + 512\,b + 13{,}448\,c = 3{,}341.58$$

By solving the equations simultaneously, the following equation of the theoretical learning curve for picking defective objects was obtained:

$$y_t = 9.647 + .684\,x - .0245\,x^2$$

The curve for this equation has the property of having the sum of squares of vertical deviations of the "y" values from this curve smaller than the corresponding sum of squares of deviations from any other curve.

Table 10. Summary Sheet of Calculations for Learning Curve

x	y	x^2	x^3	x^4	xy	x^2y	y_t
-7	.53	49	-343	2401	-3.71	25.97	3.66
-6	6.69	36	-216	1296	-40.14	240.84	4.66
-5	6.53	25	-125	625	-32.65	163.25	5.62
-4	7.83	16	- 64	256	-31.32	125.28	6.52
-3	7.69	9	- 27	81	-23.07	69.21	7.37
-2	7.89	4	- 8	16	-15.78	31.56	8.18
-1	8.89	1	- 1	1	- 8.89	8.89	8.94
0	9.19	0	0	0	0	0	9.65
1	10.94	1	1	1	10.94	10.94	10.30
2	12.86	4	8	16	25.72	51.44	10.92
3	6.86	9	27	81	20.58	61.74	11.48
4	12.31	16	64	256	49.24	196.96	11.99
5	11.44	25	125	625	57.20	286.00	12.45
6	13.75	36	216	1296	82.50	495.00	12.87
7	14.50	49	343	2401	101.50	710.50	13.23
8	13.50	64	512	4096	108.00	864.00	13.55
8	151.40	344	512	13,448	300.12	3,341.58	

Calculation of Index of Correlation

The index of correlation is a measure of how well a theoretical curve fits the data from which the curve was calculated. In calculating this index, the theoretical curve was first fitted to the observed data by the method of least squares as described in the preceding section, and second, the calculations were performed as outlined below. Figure 6 shows the observed values for which the theoretical curve and its index of correlation were calculated as being typical of the computations performed for the curves in Figures 15 through 19.

In Table 11, the "x" values represent the scores of each operator on the dexterity tests which were given. The scores were coded by subtracting 50 from each value. The "y_o" values are the average corrected numbers of picked defective objects per minute of each operator which were coded by subtracting 80 pickouts. Finally, the "y_t" values are the results obtained by substituting the "x" values of the operators into the calculated theoretical curve.

After performing the computations indicated in Table 11, the results were used to calculate the index of correlation ρ (36).

$$\rho = \sqrt{1 - \frac{s_y^2}{\sigma_y^2}}$$

where $s_y^2 = \dfrac{\sum_{i=1}^{n} (y_o - y_t)^2}{n}$ and $\sigma_y^2 = \dfrac{\sum_{i=1}^{n} (y_o^2) - \dfrac{\left[\sum_{i=1}^{n} y_o\right]^2}{n}}{n}$

$$s_y^2 = \frac{91.77}{9} = 10.196 \qquad \sigma_y^2 = \frac{1,313.00 - \frac{8,235.56}{9}}{9} = 44.22$$

$$\rho = \sqrt{1 - \frac{10.196}{44.22}} = \underline{\underline{.877}}$$

Table 11. Summary Sheet for Calculations for Index Correlation

Class	Operator	y_o	y_o^2	x	y_t	$y_o - y_t$	$(y_o - y_t)^2$
	1	22.00	484.00	37.50	18.34	3.66	13.39
1	2	17.25	297.50	23.00	12.37	4.88	23.81
	3	16.50	272.25	42.50	20.74	4.24	17.97
	1	8.75	76.50	9.50	8.13	.62	.38
2	2	7.50	56.25	17.00	10.33	-2.83	8.01
	3	.25	6.25	-16.50	3.57	-3.32	11.02
	1	4.25	18.00	3.75	6.72	-2.47	6.10
3	2	7.75	60.00	6.50	7.37	.38	.14
	3	6.50	42.25	-22.50	3.19	3.31	10.95
		90.75	1,313.00	100.75			91.77

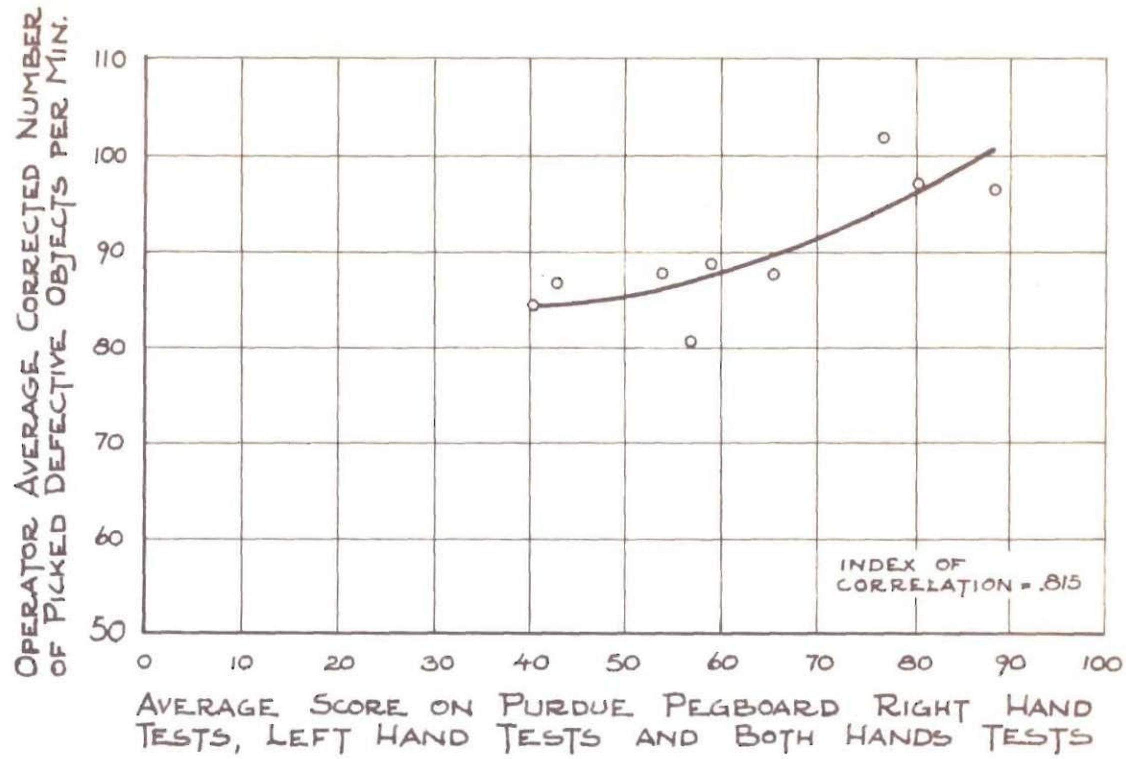

Figure 15. Average Picking Rate of Defective Objects per Operator versus Average Score on Purdue Pegboard Right Hand Tests, Left Hand Tests and Both Hands Tests

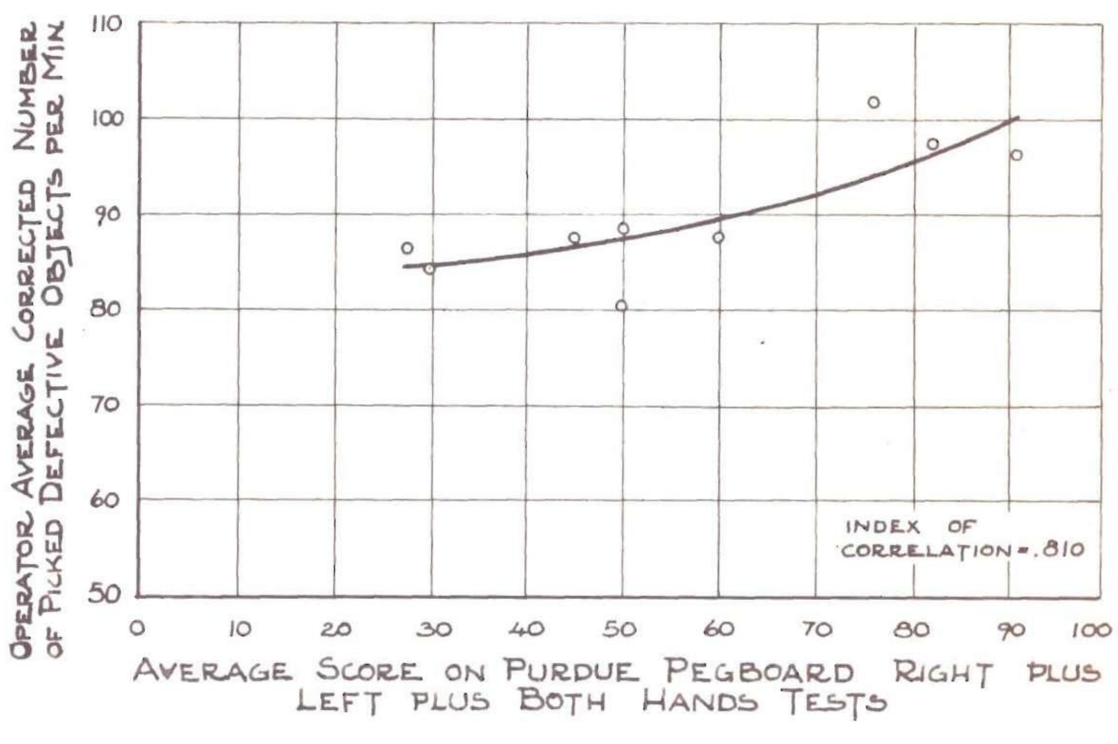

Figure 16. Average Picking Rate of Defective Objects per Operator versus Average Score on Purdue Pegboard Right plus Left plus Both Hands Tests

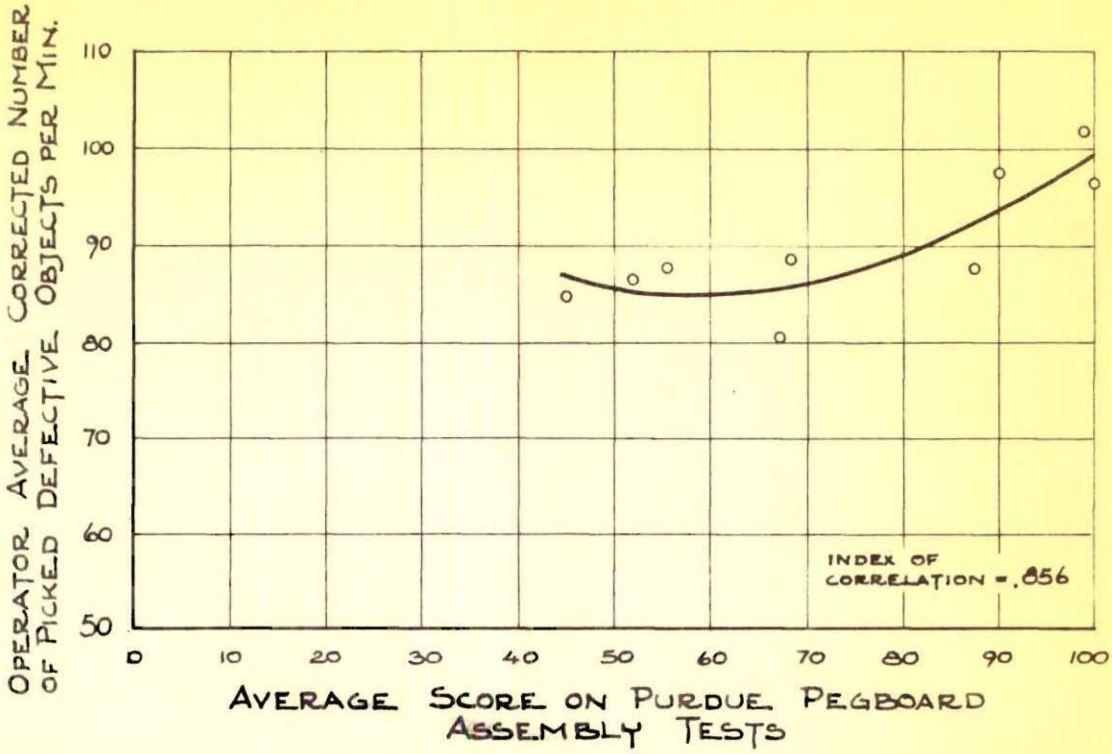

Figure 17. Average Picking Rate of Defective Objects per Operator versus Average Score on Purdue Pegboard Assembly Tests

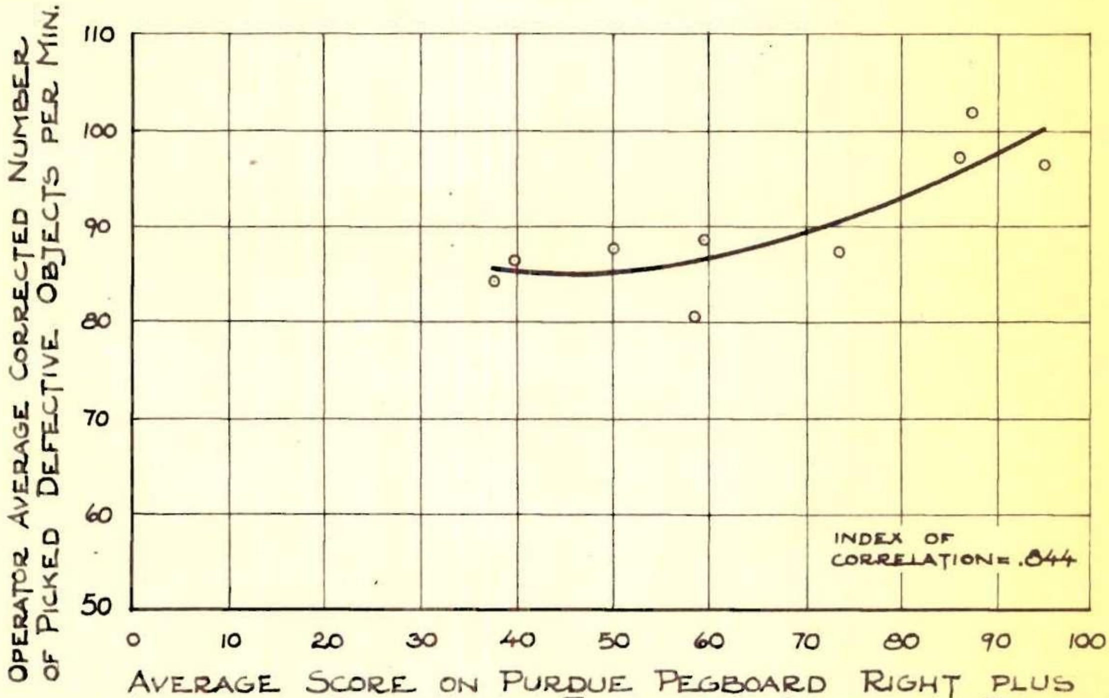

Figure 18. Average Picking Rate of Defective Objects per Operator versus Average Score on Purdue Pegboard Right plus Left plus Both Hands Tests and Assembly Tests

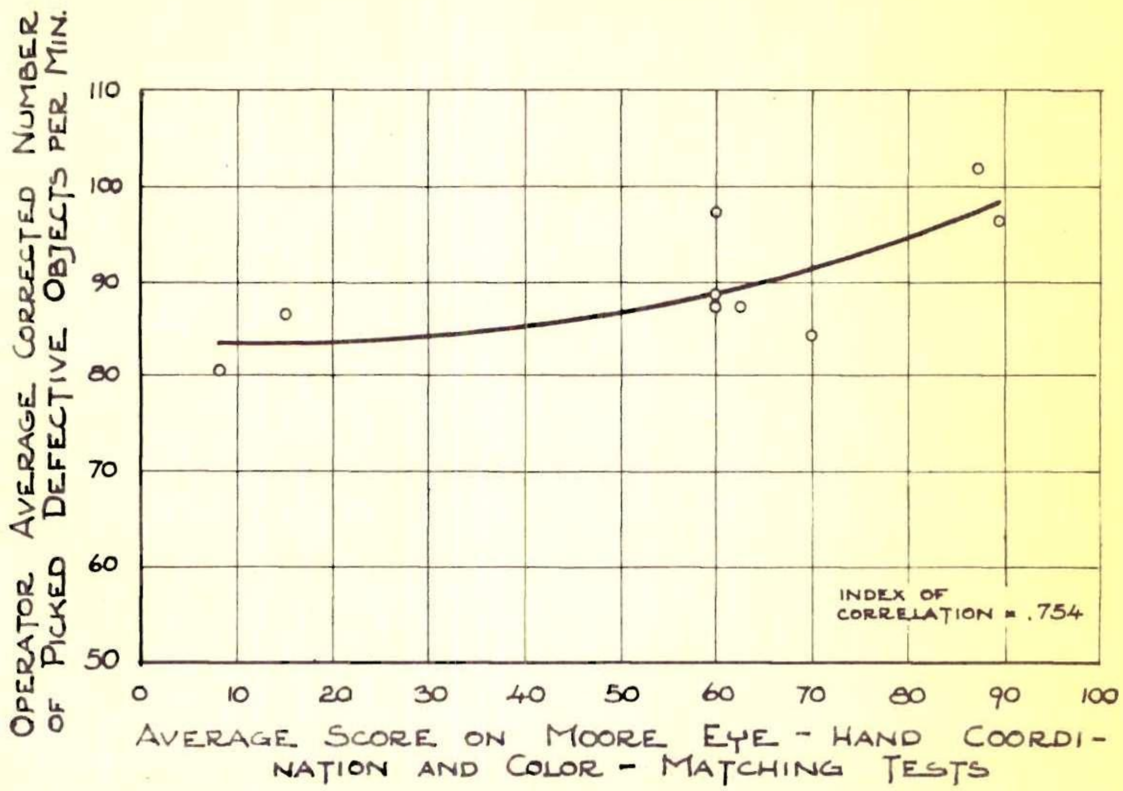

Figure 19. Average Picking Rate of Defective Objects per Operator versus Average Score on Moore Eye-Hand Coordination and Color-Matching Tests

Analysis of Variance

In Table 12, the sources of variance, their numbers of levels in the experiment, and Model designations were shown together with the superscripts and subscripts indicating a particular (or general) level of each factor in the analysis. Using the notation of Scheffé (37) the observations were regarded as being of a form expressed by the following model equation

$$x_{ijklm} = \mu + \alpha_{i}^{C} + a_{ij}^{O} + \alpha_{k}^{S} + \alpha_{l}^{D} + \alpha_{ik}^{CS} + \alpha_{il}^{CD} +$$

$$a_{ijk}^{OS} + a_{ijl}^{DO} + \alpha_{kl}^{DS} + \alpha_{ikl}^{CDS} + a_{ijkl}^{DOS} + a_{ijklm}^{R}$$

According to the superscripts of the model equation which indicates the possible main effects and interactions, Tables 13 and 14 were constructed (38). Table 13 gives the equations from which the sums of squares were derived; their magnitudes are shown in Table 14. The mean squares were calculated by dividing each sum of squares by their particular degrees of freedom. The expected mean squares were tabulated to show which ratios of mean squares are appropriate for testing the various null hypotheses by the use of the Fisher F distribution. It can be seen, for instance, that the D x O x S interaction was tested against the Residual, while the D main effect was tested against the D x O interaction. The O x S; D x O; D x S and C x D x S interactions were tested against the pooled mean square of Residual and D x O x S interaction, which was obtained by dividing their added sums of squares by the sum of their degrees of freedom. For the significance test of the O main effect an approximation was employed as described by Mood (39).

The ratios were compared with values taken from tables for F distributions by means of their appropriate degrees of freedom and were rejected when their magnitude was greater than those of the table values at the indicated probability level. Rejection of the ratio means that the source of variance was significant at the indicated probability level.

Table 12. Analysis of Variance Table

Source of Variance	Super-Script	Sub-Script	Model	Symbol	No. of Levels
Class	C	i	I	α_i^C	3
Operator	O	j	II	a_{ij}^O	3
Density - Speed	S	k	I	α_k^S	4
Damage Content	D	l	I	α_l^D	2
Replicate	R	m	II	a_{ijklm}^R	2

Table 13. Components of Analysis of Variance Table, Part I

Source of Variance	Degrees of Freedom	Components of Sum of Squares
C	2	$\sum_{i} S^2_{i....}/JKLM - S^2_{.....}/IJKLM$
O	6	$\sum_{ij} S^2_{ij...}/KLM - \sum_{i} S^2_{i....}/JKLM$
S	3	$\sum_{k} S^2_{..k..}/IJLM - S^2_{.....}/IJKLM$
D	1	$\sum_{l} S^2_{...l.}/IJKM - S^2_{.....}/IJKLM$
C x S	6	$\sum_{ik} S^2_{i.k..}/JLM - \sum_{i} S^2_{i....}/JKLM - \sum_{k} S^2_{..k..}/IJLM + S^2_{.....}/IJKLM$
C x D	2	$\sum_{il} S^2_{i..l.}/JKM - \sum_{i} S^2_{i....}/JKLM - \sum_{l} S^2_{...l.}/IJKM + S^2_{.....}/IJKLM$
O x S	18	$\sum_{ijk} S^2_{ijk..}/LM - \sum_{ij} S^2_{ij...}/KLM - \sum_{ik} S^2_{i.k..}/JLM + \sum_{i} S^2_{i....}/JKLM$
D x O	6	$\sum_{ijl} S^2_{ij.l.}/KM - \sum_{ij} S^2_{ij...}/KLM - \sum_{il} S^2_{i..l.}/JKM + \sum_{i} S^2_{i....}/JKLM$
D x S	3	$\sum_{kl} S^2_{..kl.}/IJM - \sum_{k} S^2_{..k..}/IJLM - \sum_{l} S^2_{...l.}/IJKM + S^2_{.....}/IJKLM$

Table 13. Components of Analysis of Variance Table, Part I
(Continued)

Source of Variance	Degrees of Freedom	Components of Sum of Squares
C x D x S	6	$\sum_{ikl} S^2_{i.kl.}/JM - \sum_{ik} S^2_{i.k..}/JLM - \sum_{il} S^2_{i..l.}/JKM - \sum_{kl} S^2_{..kl.}/IJM + \sum_{i} S^2_{i....}/JKLM + \sum_{k} S^2_{..k..}/IJLM + \sum_{l} S^2_{...l.}/IJKM - S^2_{.....}/IJKLM$
D x O x S	18	$\sum_{ijkl} S^2_{ijkl.}/M - \sum_{ijk} S^2_{ijk..}/LM - \sum_{ijl} S^2_{ij.l.}/KM - \sum_{ikl} S^2_{i.kl.}/JM + \sum_{ij} S^2_{ij...}/KLM + \sum_{ik} S^2_{i.k..}/JLM + \sum_{il} S^2_{i..l.}/JKM - \sum_{i} S^2_{i....}/JKLM$
R	72	$\sum_{ijklm} X^2_{ijklm} - \sum_{ijkl} S^2_{ijkl.}/M$
Total	143	$\sum_{ijklm} X^2_{ijklm} - S^2_{.....}/IJKLM$

Table 14. Components of Analysis of Variance Table, Part II

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F - Test
C	2	530,374	265,187	$\sigma_o^2 + \sigma_{DOS}^2 + K\sigma_{DO}^2 + L\sigma_{OS}^2 + KL\sigma_O^2 + JKL\sigma_C^{2\prime}$	$\frac{265,187}{17,671} = 15.00$**
O	6	106,026	17,671	$\sigma_o^2 + \sigma_{DOS}^2 + K\sigma_{DO}^2 + L\sigma_{OS}^2 + KL\sigma_O^2$	$\frac{17,671}{4,849} = 3.64$*
S	3	395,190	131,730	$\sigma_o^2 + \sigma_{DOS}^2 + L\sigma_{OS}^2 + IJL\sigma_S^{2\prime}$	$\frac{131,730}{2,521} = 52.25$***
D	1	163,216	163,216	$\sigma_o^2 + \sigma_{DOS}^2 + K\sigma_{DO}^2 + IJK\sigma_D^{2\prime}$	$\frac{136,216}{3,092} = 52.78$***
C x S	6	6,069	1,011	$\sigma_o^2 + \sigma_{DOS}^2 + L\sigma_{OS}^2 + JL\sigma_{CS}^{2\prime}$	$\frac{1,011}{2,521} = .40$
C x D	2	7,411	3,705	$\sigma_o^2 + \sigma_{DOS}^2 + K\sigma_{DO}^2 + JK\sigma_{CD}^{2\prime}$	$\frac{3,705}{3,092} = 1.20$
O x S	18	45,379	2,521	$\sigma_o^2 + \sigma_{DOS}^2 + L\sigma_{OS}^2$	$\frac{2,521}{1,427} = 1.77$*
D x O	6	18,554	3,092	$\sigma_o^2 + \sigma_{DOS}^2 + K\sigma_{DO}^2$	$\frac{3,092}{1,427} = 2.17$

Table 14. Components of Analysis of Variance Table, Part II
(Continued)

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F - Test
D x S	3	12,435	4,145	$\sigma_o^2 + \sigma_{DOS}^2 + IJ\sigma_{DS}^{2'}$	$\frac{4,145}{1,427} = 2.90$*
C x D x S	6	7,548	1,258	$\sigma_o^2 + \sigma_{DOS}^2 + J\sigma_{CDS}^{2'}$	$\frac{1,258}{1,427} = .88$
D x O x S	18	13,744	764	$\sigma_o^2 + \sigma_{DOS}^2$	$\frac{764}{1,593} = .479$
R	72	114,690	1,593	σ_o^2	
Total	143	1,420,636	993,452		

* Denotes significance at the .05 level
** Denotes significance at the .01 level
*** Denotes significance at the .001 level

Calibration of the Gate

In Chapter II one-hundred per cent density of the objects on the belt was described as an experimentally derived figure for which no standard measure is available. This figure was established by placing the objects in such a manner in a unit area on the belt that there was no room for more objects without their having to rest on top of others. Fifteen consecutive times the objects, placed in a unit area of 72 sq. inch, were weighted and from the observed values the arithmetic mean was calculated to be 175.0 grams.

From a calculation of the standard deviation (σ_x = 6.56 grams) and the number of samples taken, the standard error from the observed mean was derived as follows:

$$\sigma_{\bar{x}} = \frac{\sigma_x}{\sqrt{n}}$$

substituted

$$\sigma_{\bar{x}} = \frac{6.56}{\sqrt{15}} = 1.70 \text{ grams}$$

This error was below 1 per cent of the mean which was considered to be satisfactory in the experiments.

With a definition of 100 per cent density the gate opening was calibrated for each of the tested densities at their respective belt speeds. No calibration mark was made before 15 consecutive readings falling within 1 per cent of the specific density level were obtained. The readings were taken by means of a frame (72 sq. inch) which was placed on the belt at a location marked on the apron.

APPENDIX III

GRAPHICAL ANALYSIS

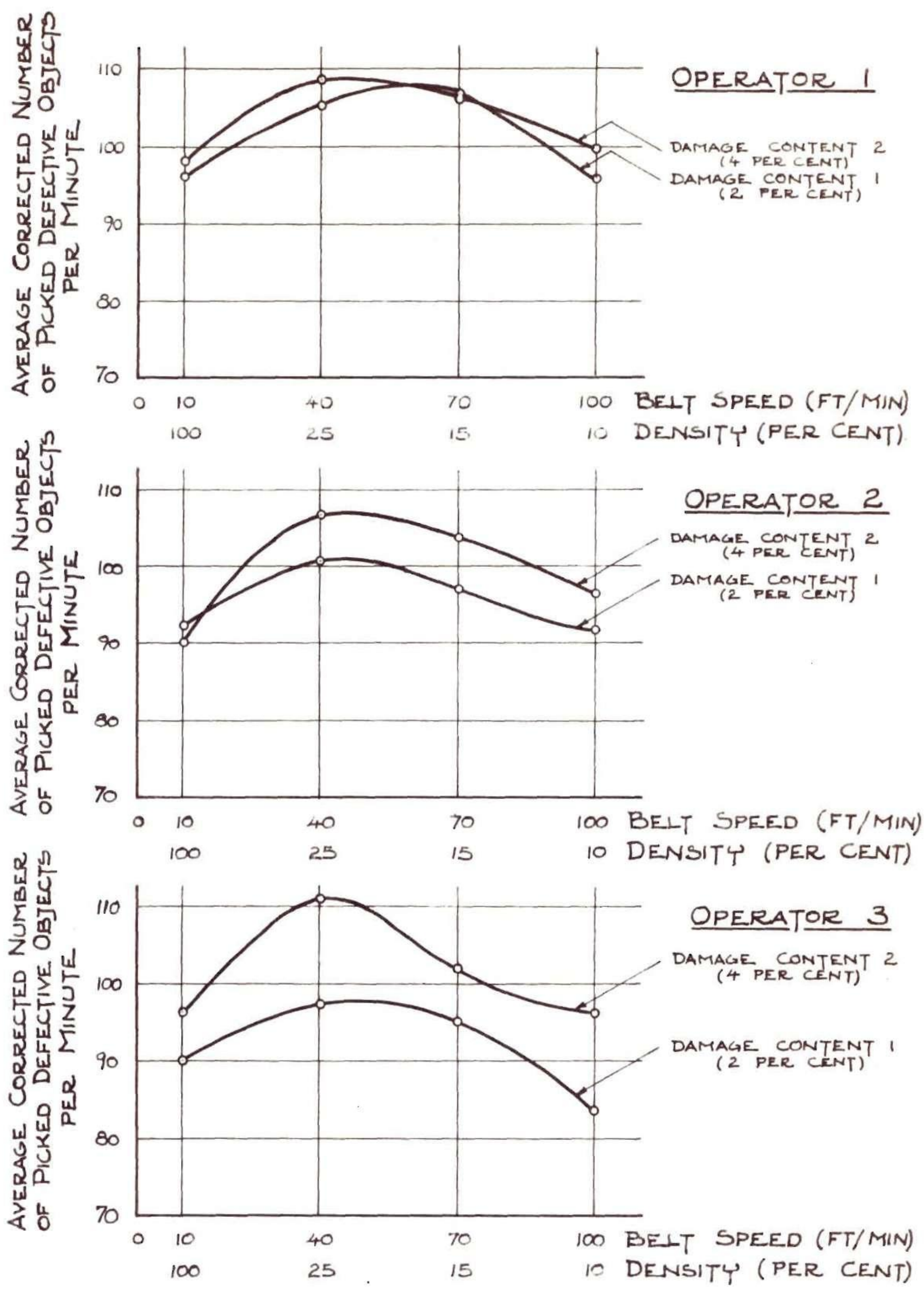

Figure 20. Average Picking Rates of Defective Objects versus Density - Belt Speed Combinations for Damage Contents and Operators of Class 1

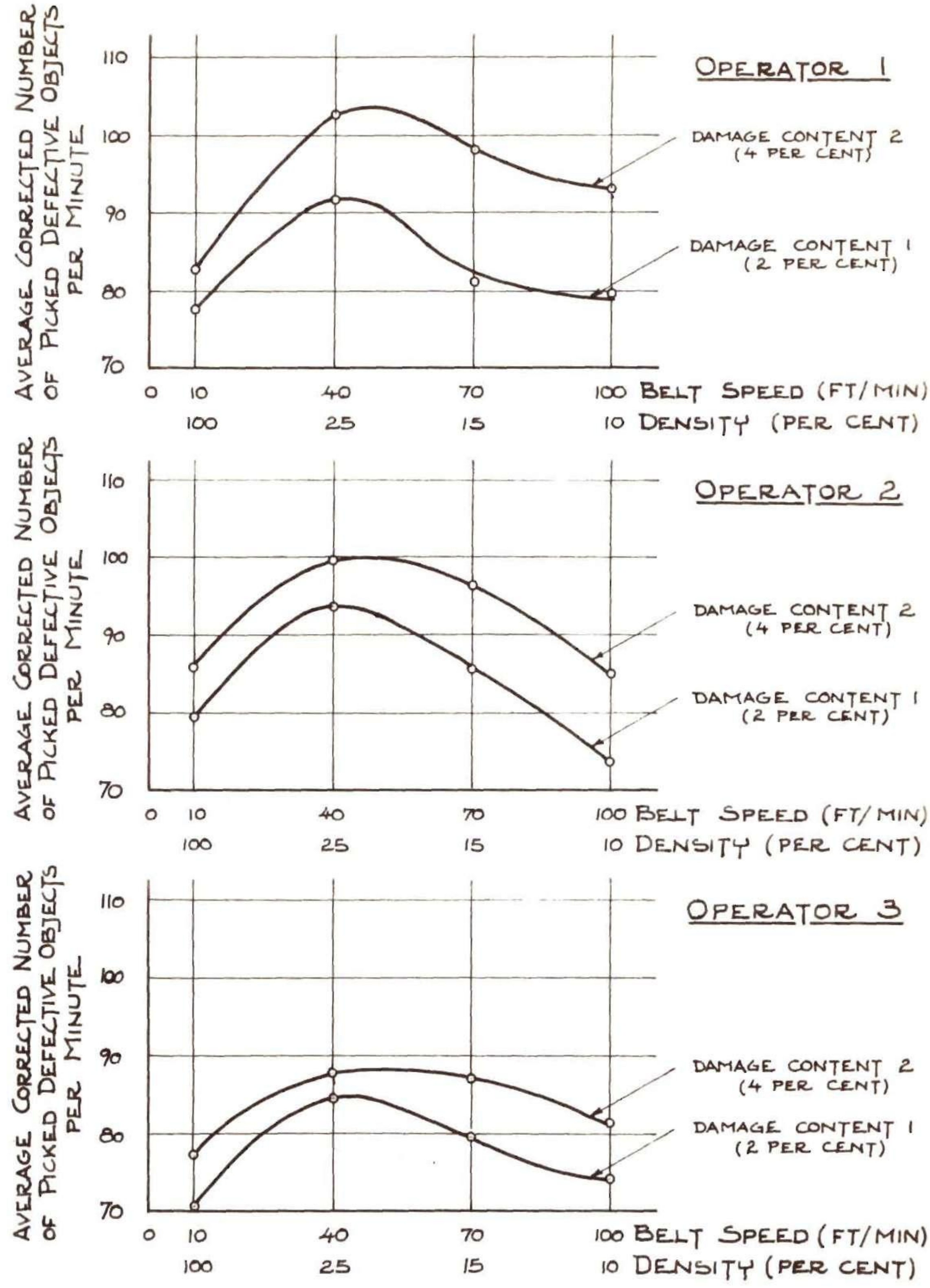

Figure 21. Average Picking Rates of Defective Objects versus Density - Belt Speed Combinations for Damage Contents and Operators of Class 2

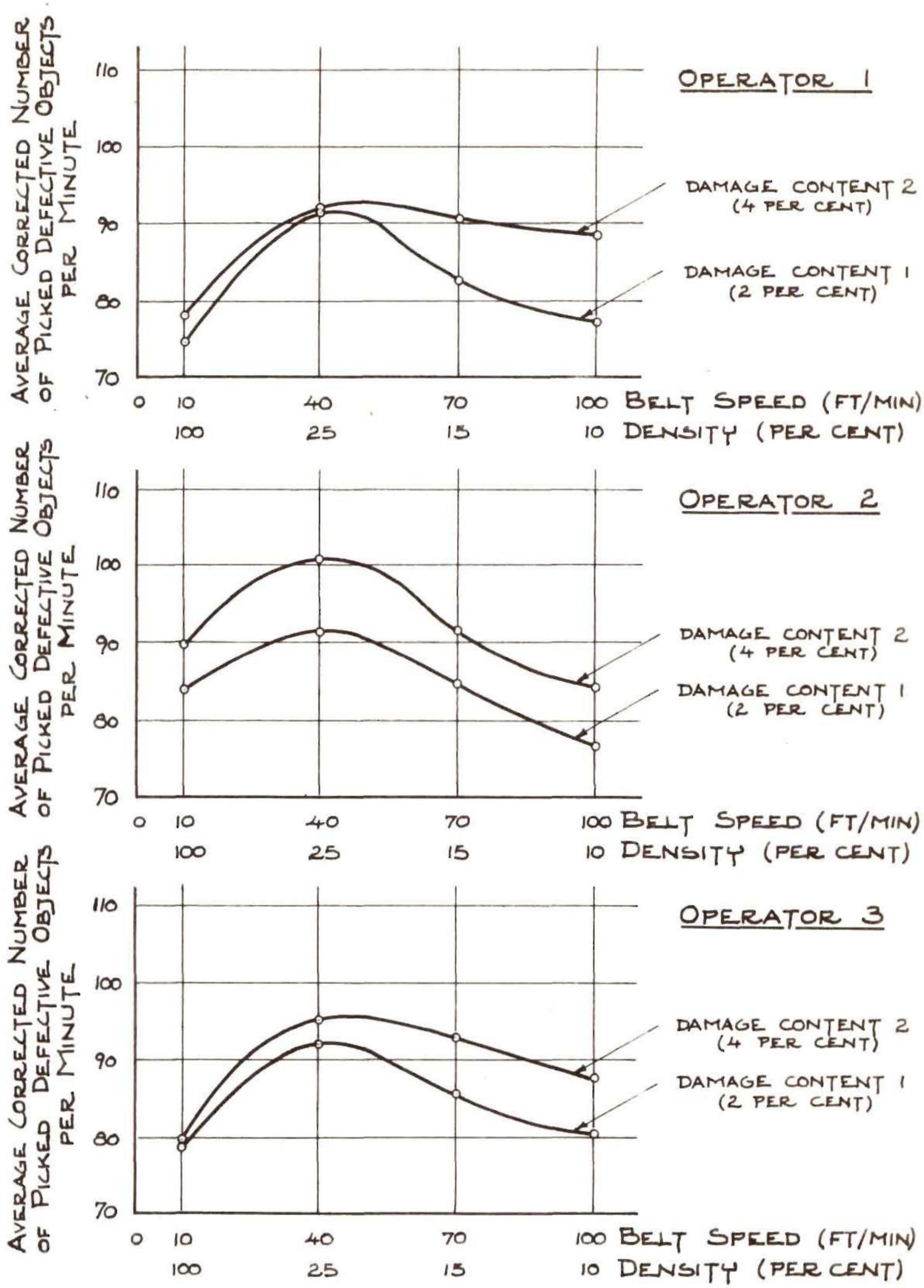

Figure 22. Average Picking Rates of Defective Objects versus Density - Belt Speed Combinations for Damage Contents and Operators of Class 3

Table 15. Ranges of Density - Belt Speed Combinations for Optimum Picking Rates of Defective Objects

Class	Operator	Range of Density in Per Cent for Maximum Number of Picked Defective Objects Per Minute - 1, at Damage Contents of 2 Per Cent	4 Per Cent	2 and 4 Per Cent	Range of Belt Speed in Feet Per Minute for Maximum Number of Picked Defective Objects Per Minute - 1, at Damage Contents of 2 Per Cent	4 Per Cent	2 and 4 Per Cent
	1	21.7-14.7	25.6-18.2	21.7-18.2	46-68	39-55	46-55
1	2	27.7-18.8	25.6-17.2	25.6-18.8	36-53	39-58	39-53
	3	31.2-16.6	27.7-19.2	27.7-19.2	32-60	36-52	36-52
	1	28.6-20.0	27.7-17.8	27.7-20.0	35-50	36-56	36-50
2	2	28.6-19.6	26.3-17.2	26.3-19.6	35-51	38-58	38-51
	3	28.6-19.2	26.3-15.6	26.3-19.2	35-52	38-64	38-52
	1	27.7-20.0	26.3-16.1	26.3-20.0	36-50	38-62	38-50
3	2	30.3-20.8	30.3-20.4	30.3-20.8	33-48	33-49	33-48
	3	27.8-20.4	26.3-16.6	26.3-20.4	36-49	38-60	38-49
Range Common to All Operators (Optimum Range)		21.7-20.8	25.6-20.4	21.7-20.8	46-48	39-49	46-48

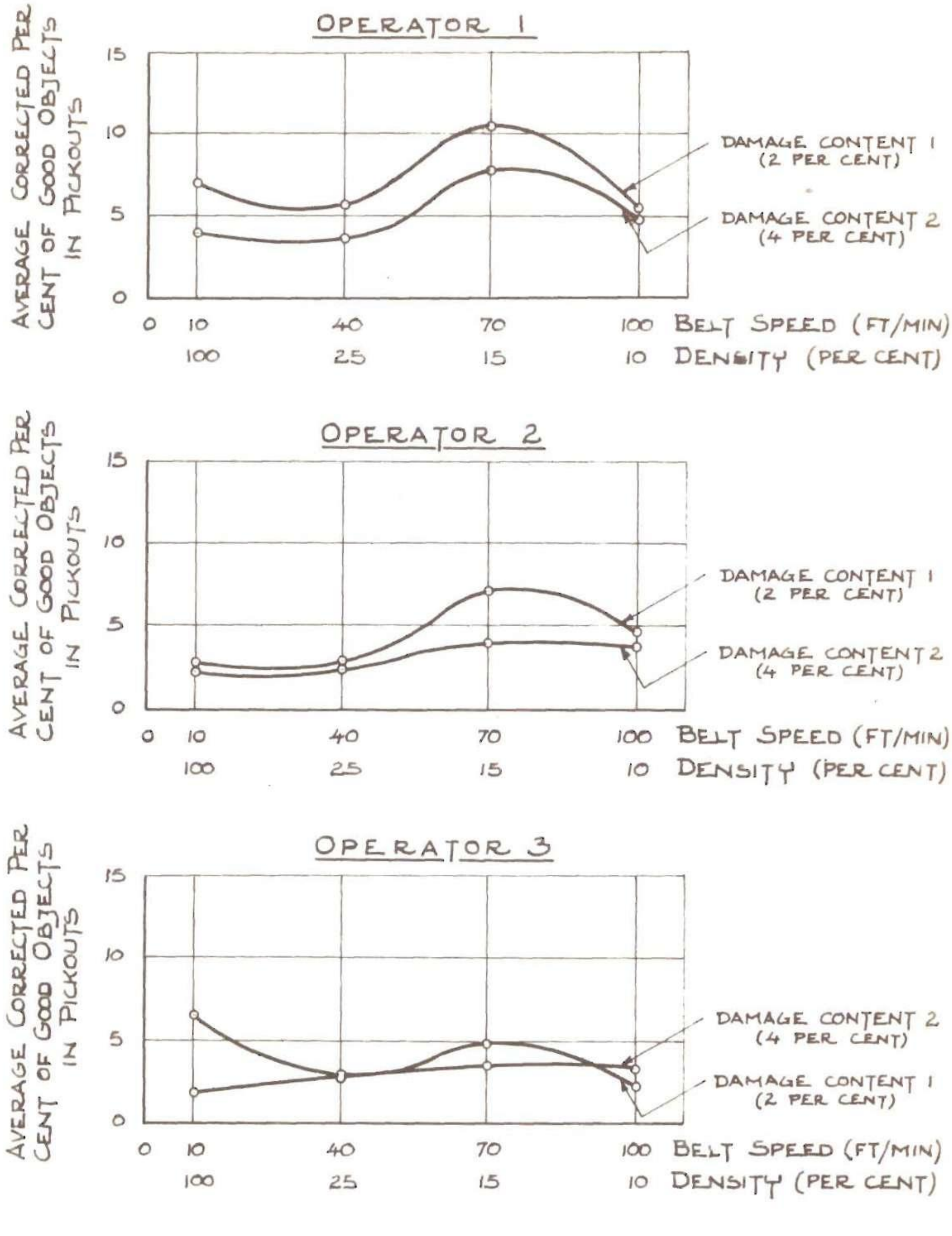

Figure 23. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Damage Contents and Operators of Class 1

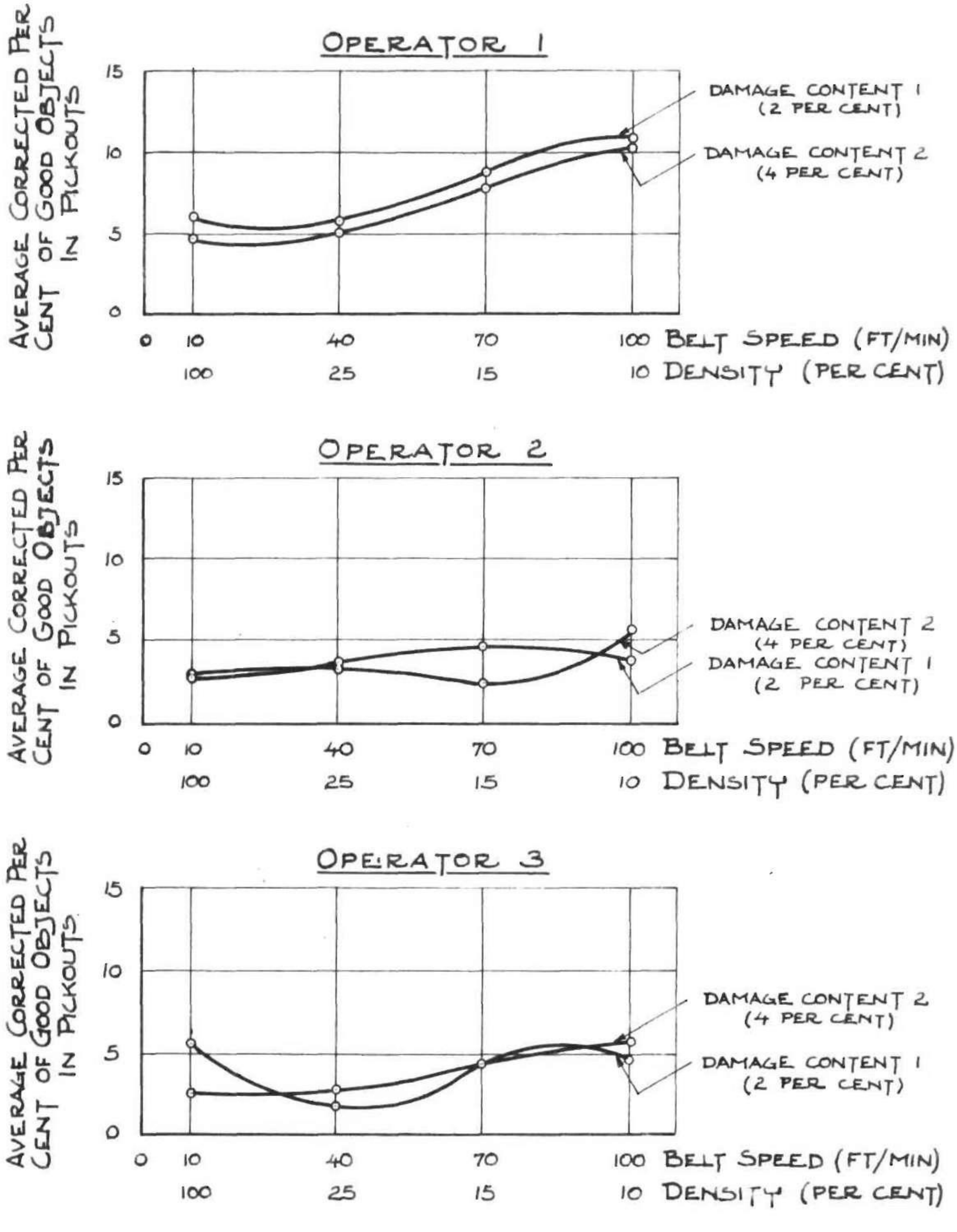

Figure 24. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Damage Contents and Operators of Class 2

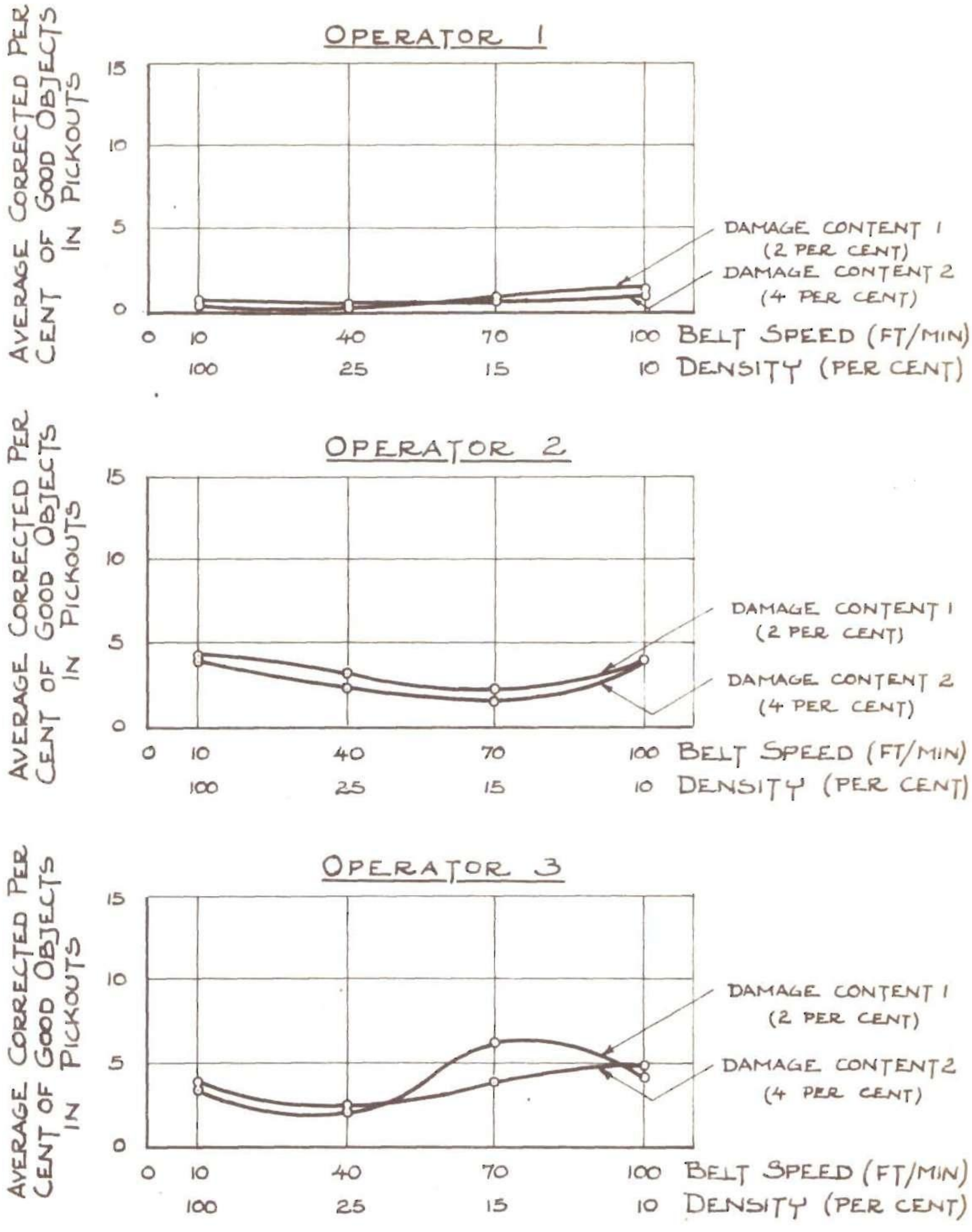

Figure 25. Average Picking Quality Expressed in Per Cent versus Density - Belt Speed Combinations for Damage Contents and Operators of Class 3

Table 16. Ranges of Density - Belt Speed Combinations for High Quality in the Pickouts

Class	Operator	Range of Density in Per Cent for Minimum Per Cent of Good Objects in Pickouts + 1 Per Cent, at Damage Contents of			Range of Belt Speed in F.P.M. for Minimum Per Cent of Good Objects in Pickouts + 1 Per Cent, at Damage Contents of		
		2 Per Cent	4 Per Cent	2 and 4 Per Cent	2 Per Cent	4 Per Cent	2 and 4 Per Cent
1	1	45.4-22.7	55.5-25.0	45.5-25.0	22-44	18-40	22-40
	2	100.0-24.3	100.0-23.3	100.0-24.3	10-41	10-43	10-41
	3	31.2-19.2	100.0-25.0	31.2-25.0	32-52	10-40	32-40
2	1	100.0-22.2	100.0-23.8	100.0-23.8	10-45	10-42	10-42
	2	100.0-29.4	20.0-12.5	None	10-34	50-80	None
	3	100.0-21.7	33.3-20.8	33.3-21.7	10-46	30-48	30-46
3	1	100.0-18.2	100.0-16.6	100.0-18.2	10-55	10-60	10-55
	2	20.0-12.1	22.7-12.1	20.0-12.1	50-82	44-82	50-82
	3	38.5-20.8	41.6-17.8	38.5-20.8	26-48	24-56	26-48
Range Common to All Operators (Optimum Range)		None	None	None	None	None	None

Economy Study of the Effect of Good Objects in the Total Pickouts Upon the Costs of Hand Quality Picking

The study is based upon Spanish-type peanuts and the economic conditions of the year 1952 (40).

Value of edible peanuts	= .20 \$/lbs.
Value of defective peanuts used for oil stock	= .11 \$/lbs.
Loss in value of good peanuts placed in the pickouts	= .09 \$/lbs.
Average total pickout rate per operator	= 70 kernels per min.
Average per cent good peanuts in pickouts	= 5 per cent
Average number of kernels per pound of Spanish peanuts	= 1,500 kernels
Assumed working time per day	= 8 hours
Loss in value due to good peanuts in total pickouts per day per operator	$= \frac{70 \times .05 \times 60 \times 8 \times .09}{1{,}500}$
	= .10 \$ per day per operator

A total cost of only .10 \$ per working day per operator due to 5 per cent good peanuts in the total pickouts can be neglected in further economy considerations.

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